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STICKY PRICES IN THE UNITED STATES

by

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Massachusetts Institute of Technology

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ABSTRACT:

It has often been argued that prices are sticky in the United States. However, the empirical papers that have claimed to support this view have not reflected any formal behavioral theory. This paper presents a theory that justified price stickyness; namely that firms, fearing to upset their customers, attribute a cost to price changes. The rational expectations equilibrium of an economy with many such firms is presented, estimated with postwar U.S. data and tested against alternative hypotheses. The results largely support the model. Furthermore, the hypothesis that prices are not sticky is rejected by U.S. data.

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I. Introduction

It is often argued that prices are sticky in the United States. In particular, various empirical papers have claimed to provide evidence that supports this view. However, these empirical papers have suffered from one major common flaw. None of them estimated equations that represented a formal theory. Therefore, their results are very hard to interpret.[1/] In general these studies have assumed that prices adjust at a constant rate to their desired value. The desired value was then assumed to depend on both the current and lagged values of a variety of variables (unit labor costs, the level of capacity utilization, the rental price of capital, the level of output and the level of capital are but examples of these variables). Then these authors estimated equations that made current prices a function of lagged prices and the variables purported to influence the desired prices. The fact that in the U.S. lagged prices help to explain current prices was taken by these authors as evidence that prices are sticky. The papers by Eckstein and Fromm [1968], and De Menil [1974] as well as the MPS model as reported by Hymans [1972], De Menil and Enzler [1972] and McCallum [1978] proceed exactly as outlined above. Eckstein and Wyss [1972] who concentrate on individual prices, also make the desired prices a function of a variety of variables and, instead of allowing lagged prices to explain current prices, they estimate their price equations by correcting for first order serial correlation. It is hard to interpret this procedure, but it also would appear consistent with some form of price rigidity.

Of course, just the fact that lags of the variables relevant in explaining "desired" prices are significant explanators of current prices seems to point towards the existence of some sort of rigidity. This view is not shared by Sahling [1977]. He explains current prices by current and lagged values of various variables. He does not include lagged prices in his list of explanators of current prices. Instead, he appears to think that prices are flexible if the current and lagged rates of return on capital do not help in predicting current prices. He views prices as relatively inflexible if neither the stocks of labor nor those of capital help explain prices. He concludes that the data support the hypothesis that prices are relatively rigid.

Domberger [1979] goes one step further. He computes the "speed of adjustment" of prices towards his measure of "desired" prices for a variety of industries. He then runs a regression of the speeds of adjustment of these industries on some indicators of industry structure. Again, even though the results seem plausible, they are hard to interpret in the absence of a theory.

Many of these authors state that prices are sticky because firms face costs of changing their prices. These costs range from the objective costs of printing new price lists to the costs borne by firms as they render their customers unhappy with recurrent price changes. It turns out that if one couples the assumption that firms face costs of changing prices with assumptions about functional forms, that the set of paths for output and prices that does not reject these assumptions is fairly small. In particular, the implied stochastic processes can be estimated. Furthermore, the coefficients that result from this estimation have an

easy interpretation. Finally, the implications of the assumptions can be tested against both the hypothesis that prices adjust instantaneously and against other hypotheses which impose fewer restrictions on the paths of prices and quantities. This estimation of a model in which it is costly to change prices and the tests of this model are the purpose of this paper.

I start in Section II by presenting the model which has been introduced in Rotemberg [1981 a and b]. In this section the equilibrium of an economy in which firms with market power face quadratic costs to changing prices is computed. This equilibrium has implications for both the behavior of relative prices and for the stochastic processes governing the joint behavior of the aggregate variables (the price level, the level of output and the money stock). These implications are presented in Section III. I then proceed to test these implications. Section IV establishes that the behavior of relative prices, while consistent with the model, is not consistent with a Walrasian equilibrium with complete markets. Section V estimates the model in two versions. First, it is assumed that all the prices in the U.S. are set by price setting firms who face costs to changing prices. Then it is assumed that only those firms whose output belongs to the non-farm business sector have these characteristics. The other prices are grouped in an index which is taken to be econometrically exogenous. The extimates are compared with the predictions of the model. In general, the estimates are consistent with the model. In particular, prices are shown to be sticky in the U.S.

Then, the estimated equations are compared with less restricted equations to ascertain whether the U.S. data rejects the model. These more general specifications do not reject the equations describing money

and prices. They do, however, reject the specification of the output equation. This may be due to the neglect of the effect of relative prices on aggregate output. Section VI presents some conclusions and suggestions for further research.

II. Model

The economy consists of n monopolists indexed by i whose demand functions at time t are:

$$Q_{it} = A_{it} \left(\frac{P_{it}}{P_t} \right)^{-b_i} \left(\frac{M_t}{P_t V_t} \right)^{d_i} \qquad i = 1,\ldots,n \tag{1}$$

where Q_{it} is the quantity of good i demanded at time t, P_{it} is the price of good i at t, M_t is the level of money balances at t, while V_t and A_{it} are the values at t of two time varying taste parameters. The exponents b_i and d_i are constants. P_t is the price level at t which is given by:

$$P_t = \prod_{i=1}^{n} P_{it}^{h_i/\Sigma h_i} \tag{2}$$

In equation (1) higher real money balances lead to a larger demand for all goods. This is a natural consequence of assuming that individuals derive utility from their holdings of real money balances.

The cost to firm i of producing Q_{it} is assumed to be given by:

$$C(Q_{it}) = \frac{U_{it}}{2} P_t Q_{it}^2 \qquad i = 1, \ldots, n \tag{3}$$

where U_{it} is a time varying parameter. In particular, U_{it} could depend on the real wage at t, as in Rotemberg [1981 a and b]. The implications for the movements of relative prices, aggregate output and the price level are the

same whether a classical labor market is included in the model or not. Therefore, for simplicity, this paper will proceed as if only goods were required to produce goods in the U.S. Note that the cost functions (3) are such that the economy's production possibilities are bounded.

In the absence of costs of changing prices, firm i would change a price such that the marginal revenue from sales is equal to the marginal cost of production. This price whose logarithm is p^*_{it} is given by:

$$p^*_{it} = s_{it} + p_t + \frac{d_i}{1+b_i} (m_t - p_t - v_t) \qquad (4)$$

where $s_{it} = (a_{it} + \theta_i + u_{it}) / (1 + b_i)$

In the above expressions, lower case letters represent the logarithms of the respective upper case letters and θ_i is the logarithm of the elasticity of demand over the elasticity of demand minus one, and is therefore constant. It is now possible to approximate the difference between revenues from sales and costs of production by a quadratic function of the difference between the logarithm of the price the firm actually charges and p^*_{it}.

The key feature of this model is that price changes are assumed to be costly. The presence of these costs has been hypothesized by various authors, including Barro [1972], Nordhaus [1972], Sheshinski and Weiss [1977] and Mussa [1978]. These costs are of two types. First, there is a fixed cost per price change which includes the physical cost of changing posted prices. Second, and in my view more importantly, there is a cost that captures the negative effect of price changes, particularly price increases on the reputation of firms. As stated in Stiglitz [1979], under imperfect information customers will tend to cater to firms with relatively stable price paths and avoid those firms who change their prices often and by large amounts. The reputation of firms is

presumably more affected by large price changes, which are very noticeable, than by small price changes. Therefore the costs of price adjustments are assumed to be quadratic in the percentage change of prices.

The firms are now assumed to maximize the expected discounted value of the difference between revenues from sales and the sum of production costs and costs of changing prices. This expected discounted value can be approximated by:

$$E_t \sum_{\tau=t}^{\infty} \rho^{\tau} [\Pi(p^*_{i\tau}) - k_i(p_{i\tau} - p_{i\tau}^*)^2 - c_i(p_{i\tau} - p_{i\tau-1})^2] \qquad (3)$$

where E_t denotes the operator that takes expectations conditional on information available at time t, and $\Pi(p^*_{it})$ is the difference between the revenues and the costs of production that would accrue to the firm if it charged P^*_{it}. The constant k_i is the second term of the Taylor expansion of profits around p^*_{it}, while ρ is the discount factor and c_i is a parameter. At p^*_{it}, the derivative of profits with respect to prices, is zero and, therefore, the linear term is excluded from (5).

Maximizing expression (5) is equivalent to minimizing:

$$E_t \sum_{\tau=t}^{\infty} \rho^{\tau} [(p_{i\tau} - p^*_{i\tau})^2 - \frac{c_i}{k_i}(p_{i\tau} - p_{i\tau-1})^2] \qquad (6)$$

Note that the expectation at t of $p^*_{i\tau}$, the price the firm would charge in the absence of costs to changing prices, is independent of the firm's actions.

I now assume that:

$$\frac{c_i}{k_i} = c \qquad \text{for all } i$$

This assumption imposes one nonlinear restriction across the five firms

specific parameters. It is trivially satisfied when b_i, d_i, c_i, A, and u_i are identical across firms. This assumption is sufficient to ensure that all firms adjust their prices at the same speed.

The minimization of (6) is a recursive optimal control problem[2/] which leads to the following path for the prices that firm i expects to charge:

$$p_{it/t+k} = \alpha p_{it/t+k-1} + \frac{1}{\beta\rho c} \sum_{j=0}^{\infty} \left(\frac{1}{\beta}\right)^j p^{*i}_{it/t+j+k}$$

$$= \alpha p_{it/t+k-1} + \frac{1}{\beta\rho c} \sum_{j=0}^{\infty} \left(\frac{1}{\beta}\right)^j [s^i_{it/t+j+k} + p^i_{t/t+j+k}$$

$$+ g_i(m^i_{t/t+j+k} - p^i_{t/t+j+k} - v^i_{t/t+j+k})]$$

$$k = 0, 1, \ldots \infty \qquad (7)$$

where: $g_i = \dfrac{d_i}{1 + b_i}$

The superscript i denotes an expectation made by firm i. The quantity $p^i_{t/t+j}$ is the expectation held at t by firm i of the logarithm of the price level at t+j, while $p^i_{t/t+j}$ is the logarithm of the price that firm i expects to charge at t+j. The behavioral constants α and β obey the following equations:

$$\alpha < 1 < \beta$$

$$\alpha + \beta = 1/\rho c + 1/\rho + 1 \qquad (8)$$

$$\alpha\beta = 1/\rho \qquad (9)$$

Therefore,

$$(1 - \alpha)(\beta - 1) = 1/\rho c \qquad (10)$$

At t, firms actually change the leading element of the sequence given by (7), namely $p_{it/t}$. In general, (7) can be interpreted as saying that, because price changes are costly, the firms will move their prices slowly from their previous price to the expected p^*_{it}'s.

The rational expectations equilibrium of this economy can now be computed. The assumption of rational expectation requires that the firms know at t the mathematical expectation of the future values of the exogenous variables m, v and s.

At time t the firms have an expectation of the prices they will charge in the future. These are the prices the firms would actually charge in the future if they did not revise their expectations of p, m, v, and s. These expected future prices can be condensed to form the mathematical expectation of the future price levels. This mathematical expectation depends on the path of price levels expected by firms. The assumption of rationality of expectations insures that the mathematical expectation of the future price levels is equal to the future price levels expected by firms.

As shown in Rotemberg [1981 a and b], this rational expectations equilibrium can be described by the following equation:

$$p_{t/t+k} = \alpha p_{t/t+k-1} + \frac{1}{\beta\rho c} \sum_{j=0}^{\infty} \left(\frac{1}{\beta}\right)^j S_{t/t+j+k} + p_{t/t+k+j} + D(m_{t/t+k+j} - p_{t/t+k+j} - v_{t/t+k+j}) \qquad (11)$$

where: $S = \sum_i k_i s_{it} / \sum_i k_i$

$D = \sum_i g_i k_i / \sum_i k_i$

and $m_{t/t+j}$ is the mathematical expectation of m_{t+j} conditional on all information available at t. Therefore,

$$\left(1 - \alpha L + \frac{1}{\beta\rho c(1 - 1/\beta L}\right) p_{t/t+k} = \frac{D}{\beta\rho c(1 - 1/\beta L)} (m_{t/t+k} - v_{t/t+k} + S_{t/t+k}/D) \qquad (12)$$

where L is the log operator such that $Lp_{t/t+k} = p_{t/t+k-1}$. Hence, making use of the fact that agents do not expect their prices to diverge infinitely from the optimal prices in the far future:

$$p_{t/t+k} = \gamma p_{t/t+k-1} + \frac{D}{\delta\rho c} \sum_{j=0}^{\infty} \left(\frac{1}{\gamma}\right)^j (m_{t/t+k+j} - v_{t/t+k+j} + S_{t/t+k+j}/D) \quad (13)$$

where:

$$\gamma + \delta = D/\rho c + 1/\rho + 1 \quad (14)$$

$$\gamma\delta = 1/\rho \quad (15)$$

and therefore

$$(\delta - 1)(1 - \gamma) = D/\rho c \quad (16)$$

Equation (13) describes the path of the price levels expected at t. The actual price levels are given by the sequence $p_{t/t}$. That is, new information changes the whole path of expected price levels including the realized price levels. It turns out that $(m_t - v_t + S_t/D)$ is the price level that would prevail at t in the absence of costs of changing prices. Therefore (13) can be interpreted as saying that prices adjust gradually towards their expected target.

I define an index of aggregate output Y_t [3/]:

$$Y_t = \sum_i \frac{P_{it} Q_{it}}{P_t} \quad (17)$$

Recalling that in this equilibrium model, output is always equal to output demanded:

$$Y_t = \sum_i A_{it} \frac{P_{it}}{P_t} \left(\frac{P_{it}}{P_t}\right)^{-b_i} \left(\frac{M_t}{P_t V_t}\right)^{d_i}$$

For the purpose of estimating output equations, I will assume that d_i is constant across firms and equal to d and that A_{it} is time invariant. Further, I will approxi

$\Sigma\left(\frac{P_{it}}{P_t}\right)^{1-b_i} A_i$ by a constant independent of time. That is, I approximate a weighted sum of all relative prices by a constant. This will be valid as long as relative prices do not fluctuate too widely. This approximation makes the index of aggregate output independent of relative prices. Then

$$y_t = f + d\,(m_t - p_t - v_t) \tag{18}$$

where:

$$f = \log \sum_i A_i \left(\frac{P_{it}}{P_t}\right)^{1-b_i}$$

Note that abrupt changes in the quantity of money will lead to only gradual changes in the price level and, therefore, to changes in output by (18).

III. Testable Implications

I will present three testable implications of the model. In the first place, the model implies restrictions on the path of the changes in relative prices. The paths that satisfy these restrictions are in sharp contrast to those that would unfold in a competitive economy in which price changes were costless. Second, the model is consistent only with certain paths for the price level and output when money is assumed to follow a univariate autoregressive process. Third, it permits only certain paths for the price level and output when the prices of food and energy are assumed to be econometrically exogenous.

a) Correlation of changes in relative prices

In this model, relative prices can change for two reasons. First, they will change when any factor underlying long-run relative prices changes. That is, when the intensity of demand A_i for a particular good falls relative to the intensity of demand for other goods, or when that good becomes relatively cheaper to produce (i.e., U_i falls), then the relative price of the good will fall. Second, relative prices will change in response to aggregate nominal disturbances as long as g_i is different across firms. Changes in money, for instance, change real money balances as the price level adjusts slowly. The effect of this increase in the demand for good i depends on g_i and, hence, the responsiveness of individual prices to changes in money balances hinges on the size of g_i.

Furthermore, these changes in relative prices will, in general, be correlated over time. This correlation will be illustrated by two examples. In the first example, only the long run determinants of relative prices will move over time, while in the second example, only money balances will be time varying.

Example 1. The effect of a real disturbance

Let there be two firms, a constant money supply and constant v. Let:

$$s_{1t} = s_{1t-1} + \varepsilon_t \tag{19}$$

where the ε_t's are independently identically distributed normal variates with mean zero and variance σ^2_ε. That is, either the demand intensity for good i or the costs of good i follow a random walk. Further, to make S

constant, it is assumed that:

$$s_{2t} = \frac{(h_1 + h_2)S}{h_2} - \frac{h_1}{h_2} s_{1t} \tag{20}$$

A positive ε, therefore, leads to an increase in p_1, and a decrease in p_2. Finally, I assume that the price level has already reached its steady state level so that:

$$p_t = m - v + S/D \tag{21}$$

Then, by using (6)

$$p_{1t} = \alpha p_{1t-1} + (1-\alpha)(s_{1t-1} + \varepsilon_t) + (1-\alpha)(m - v + \frac{d_1}{1+b_1} \frac{S}{D}) \tag{22}$$

and

$$p_{2t} = \alpha p_{2t-1} + (1-\alpha)(s_{2t-1} - \frac{h_1}{h_2} \varepsilon_t) + (1-\alpha)(m - v + \frac{d_2}{1+b_2} \frac{S}{D}) \tag{23}$$

Note that in the long run, the difference in relative prices is exactly $s_{1t} - s_{2t}$.

By applying (6) to both the period t-1 and the expectation held at t of the prices at t+1, one obtains the changes in relative prices as:

$$(p_{1t} - p_{2t}) - (p_{1t-1} - p_{2t-1}) = \alpha(1-\alpha)[s_{1t} - s_{2t} - (p_{1t-1} - p_{2t-1})]$$

$$+ (1-\alpha)\varepsilon_t(1 + \frac{h_1}{h_2}) \tag{24}$$

$$E_t(p_{1t+1} - p_{2t+1}) - (p_{1t} - p_{2t}) = \alpha^2(1-\alpha)[s_{1t} - s_{2t} - (p_{1t-1} - p_{2t-1})]$$

$$+ \alpha(1-\alpha)\varepsilon_t\left(1 + \frac{h_1}{h_2}\right) = \alpha[(p_{1t} - p_{2t}) - (p_{1t-1} - p_{2t-1})] \quad (25)$$

So, the expected change in relative prices between t and t+1 is equal to α times the previous relative price change. As ε increases, p_1 ought to increase and p_2 ought to decrease. Neither firm carries out the long run change instantly. Instead, they change their prices slowly to spread the costs of changing prices. This leads to changes in relative prices that are correlated over time.

Example 2. The effects of a nominal disturbance.

Let there be n firms. Let s_i and v be constant over time while m follows a random walk: [4/]

$$m_t = m_{t-1} + \eta_t \quad (26)$$

where the η_t's are normal variates with mean zero and variance σ_m^2. Then (11) gives the price level at t-1, t and the price level expected at t for t+j as:

$$p_{t-1} = \gamma p_{t-2} + (1-\gamma)(m_{t-1} - v + \frac{S}{D}) \quad (27)$$

$$p_t = \gamma^2 p_{t-2} + (1-\gamma^2)(m_{t-1} - v + \frac{S}{D}) + (1-\gamma)p_t \quad (28)$$

$$p_{t/t+j} = \gamma^{j+2} p_{t-2} + (1-\gamma^{j+2})(m_{t-1} - v + \frac{S}{D}) + (1-\gamma^{j+1})\eta_t \quad (29)$$

Then, using (6) it is possible to obtain the values for the individual prices at t-1 and t, as well as the individual prices expected at t for t+1.

$$p_{it-1} = \alpha p_{it-2} + (1-\alpha)[s_i + m_{p-1} - v + (1 - g_i)\frac{S}{D}] + (g_i + 1)\frac{\gamma}{\rho C(\beta-\gamma)}(m_{t-1} - v + \frac{S}{D} - p_{t-2}) \quad (30)$$

$$p_{it} = \alpha^2 p_{it-2} + (1-\alpha^2)[s_i + m_{t-1} - v + (1 - g_i)\frac{S}{D}] + (1-\alpha)\eta_t + (g_i - 1)\frac{\gamma}{\rho C(\beta-\gamma)}[(\alpha+\gamma)(m_{t-1} - v + \frac{S}{D} - p_{t-2}) + \eta_t] \quad (31)$$

$$p_{it/t+1} = \alpha^3 p_{it-2} + (1-\alpha^3)[(s_i + m_{t-1} - v + (1 - g_i)\frac{S}{D}] + (1-\alpha^2)\eta_t + (g_i - 1)\frac{\gamma}{\rho C(\beta-\gamma)}[(\gamma^2 + \alpha^2 + \alpha\gamma)(m_{t-1} - v + \frac{S}{D} - p_{t-2}) + (\gamma + \alpha)\eta_t] \quad (32)$$

It is now possible to analyze the path of the relative price of goods i and j. At t-1, this relative price is given by:

$$p_{it-1} - p_{jt-1} = \alpha(p_{it-2} - p_{jt-2}) = (1-\alpha)[s_i - s_j + \frac{S}{D}(g_j - g_i)] + (g_i - g_j)(\frac{\gamma}{\rho C(\beta-\gamma)})(m_{t-1} - v + \frac{S}{D} - p_{t-2}) \quad (33)$$

At t, the expression for the relative price of good i and j is:

$$p_{it} - p_{jt} = \alpha^2(p_{it-2} - p_{jt-2}) + (1-\alpha^2)[s_i - s_j + \frac{S}{D}(g_j - g_i)]$$

$$+ (g_i - g_j)(\frac{\gamma}{\rho C(\beta-\gamma)})[(\alpha+\gamma)(m_{t-1} - v + \frac{S}{D} - p_{t-2}) + \eta_t) \quad (34)$$

The expectation held at t of the relative price at t+1 can be computed from (32) as:

$$p_{it/t+1} - p_{jt/t+1} = \alpha^3(p_{it-2} - p_{jt-2}) + (1-\alpha^3)[s_i - s_j$$

$$+ \frac{S}{D}(g_j - g_i)] + (g_i - g_j)(\frac{\gamma}{\rho C(\beta-\gamma)})[(\alpha^2 + \alpha\gamma + \gamma^2)$$

$$(m_{t-1} - v + \frac{S}{D} - p_{t-2}) + (\gamma + \alpha)\eta_t] \quad (35)$$

Just as in Example 1, the long run relative price is given by:

$$s_i - s_j + \frac{S}{D}(g_j - g_i)$$

Once again, any discrepancy between the previous relative price and the long run relative price is reduced at the rate α. However, even when the relative price at t-2 is equal to the long run relative price, relative prices will move over time as a response to the difference between the price <u>level</u> at t-2 and the long run equilibrium price <u>level</u>. This movement is due to the differences in the values of g_i across firms. Those firms whose g_i is relatively large will produce products whose demand elasticity with respect to real money balances is relatively large. Therefore, they will charge higher prices as real

money balances move upwards from their long run value. This can be seen by analyzing (32). By (27), the difference between p_{t-1} and the long run equilibrium price as perceived at t-1 is proportional to $(m_{t-1} - v + \frac{S}{D} - p_{t-2})$. Therefore, (32) says that if g_i is larger than g_j, then firm i's price at t-1 will be larger relative to firm j's the lower the price level at t-1 is relative to the long run equilibrium price level.

Furthermore, the change in the relative price from t-1 to t depends both on the difference between the price level at t-1 and the long run equilibrium price level as perceived at t-1 and on the monetary innovation at t, η_t. Equation (35) demonstrates that both these factors also affect the expected change in relative prices from t to t+1. Therefore, the changes in relative prices are correlated as claimed.[5/]

This implication of the model is important because there are some powerful arguments that suggest that in a competitive economy with full markets and costless price adjustment, the changes in relative prices ought to be independent. Therefore, it makes an empirical distinction between the usual competitive model and the model of this thesis fairly straightforward.

b) The path of output and the price level when money is exogenous

The model of this thesis can be estimated and tested as long as assumptions are made about the paths of m and v. In this section, I will assume that the s_i are fixed, while m and v follow univariate autoregressive processes of low order. The firms will be assumed to know these processes and base their pricing decisions on them.

The money stock will be assumed to follow the following process:

$$\psi(L)m_t = \xi_t \tag{36}$$

where

$$\Psi(L) = 1 - \psi_1 L - \psi_2 L^2 \ldots\ldots \psi_k L^k$$

The roots of $\Psi(z) = 0$ are assumed to be greater than ρ in absolute value. The ξ_t are independent normal variates with mean zero and varaince σ_m^2 . In other words, it is assumed that money is exogenous and that no other economic variables "cause" m in the Granger sense. It turns out that money seems to be exogenous in this sense in the United States as demonstrated by Sims [1972], Feige and Pearce [1974], and also by myself in Section V of this paper. The taste for money balances will be assumed to follow a first order stochastic difference equation:

$$v_t = \lambda v_{t-1} + \nu_t \tag{37}$$

where λ is smaller than $1/\rho$, while the ν_t's are independent normal variates with mean zero and variance σ_v^2 .

Sargent [1976] has noted that when money follows a process like (36), it is impossible to distinguish models in which output depends on the levels of m and models in which output depends on the history of the unpredictable components of m. The model of price stickiness in this thesis can, however, be distinguished both from models that say only that money affects output and from those that say only that monetary innovations affect output. This is so because here money affects output by first affecting real money balances. However, the price level depends on the expected future level of money balances and

hence on the parameters ψ_i. Therefore, not all patterns in which money affects output are acceptable from the point of view of this model. Moreover, the restrictions implied by the model on the effects of money on the price level and therefore on output can be tested.

First, however, the price equation that depends on the expected levels of future money balances must be transformed so as to depend only on observables. After all, the firms make their predictions of future money balances using information on current and past levels of money balances by applying (36).

The problem is to make:

$$\sum_{j=0}^{\infty} \left(\frac{1}{\delta}\right)^j m_{t/t+j}$$

depend only on current and past levels of money balances. This problem has been solved in a pathbreaking paper by Hansen and Sargent [1980]. They proved that:

$$\sum_{j=0}^{\infty} \left(\frac{1}{\delta}\right)^j m_{t/t+j} = \{[1 - \frac{L^{-1}}{\delta} \Psi(\tfrac{1}{\delta})^{-1}\Psi(L)] \,/\, [1 - (\delta L)^{-1}]\}\, m_t$$

$$= \Psi\left(\frac{1}{\delta}\right)^{-1} [1 + \sum_{j=1}^{k-1} \left(\sum_{i=j+1}^{k} \left(\frac{1}{\delta}\right)^{i-j} \psi_i\right) L^j] m_t \qquad (38)$$

Similarly, it is easy to show that:

$$\sum_{j=0}^{\infty} \left(\frac{1}{\delta}\right)^j v_{t/t+j} = \sum_{j=0}^{\infty} \left(\frac{\lambda}{\delta}\right)^j v_t = \frac{1}{1 - \lambda/\delta}\, v_t \qquad (39)$$

which converges as long as $\frac{\lambda}{\delta} < 1$, $\lambda < \delta = \frac{1}{\rho\delta}$. Hence it converges if $\lambda < \frac{1}{\rho}$. Therefore, the price level at t is given by:

$$p_t = \gamma p_{t-1} + \frac{(\delta-1)(1-\gamma)}{\delta} \Psi \left(\frac{1}{\delta}\right)^{-1} \left[1 + \sum_{j=1}^{k-1} \sum_{i=j+1}^{k} \left(\frac{1}{\delta}\right)^{i-j} \psi_i\right) L^j \Big] m_t$$

$$+ (1 - \gamma)S + \left[\frac{(\delta-1)(1-\gamma)}{\delta - \lambda}\right] v_t \qquad (40)$$

where (16) was used to eliminate $(D/\rho c)$.

Equation (40) can be estimated along with (36), the AR process for m. Clearly, these two equations are not independent since the ψ_i's appear in both. Equation (40) is clearly a "structural" equation both in that it involves endogenous variables on the RHS and that it has a direct behavioral interpretation. However, in contrast to the usual "structural" equations of macroeconometrics, it does not correspond to one sector's behavior in one market. Instead, it is a property of an equilibrium which takes into account the behavior of n firms and many more consumers. In particular, it embodies assumptions about the demand functions of individuals, the cost functions of firms and the behavior of firms.

The coefficients γ and δ are clearly identified. Unfortunately, one cannot reconstruct D, c and ρ from knowledge of these coefficients. Instead, only D/c and ρ can be recovered by use of (14) and (15). The behavior of the aggregate variables is unaffected by a doubling of c and D. As far as the price level is concerned, it is not the variable c which captures the relative pressures on charging the "right" price and on not changing prices. Instead, it is the variable D/c that represents these relative pressures. A large value for D/c means that there is both a large effect on demand when the price level is slightly wrong, and that it is relatively inexpensive to change prices. Therefore, a large D/c leads to

relative fast adjustment, i.e., low values for γ and high values for δ.

Note that the coefficients γ and δ are independent of the monetary rule $\Psi(L)$. Therefore the estimates of γ and δ are immune to the Lucas [1976] criticism and can be used to simulate the private sector's response to various monetary rules. The variable v_t clearly constitutes an error term of (39) from the view of an econometrician since it is not observable. This, of course, does not make it difficult to estimate the parameter λ since (39) can be transformed by the usual Koyck transformation. If v_t is the only variable which makes it impossible to estimate deterministic price and output equations, then the error in the price equation ought to be proportional to the error in the output equation (18). At least the errors of both the output equation and the price equation ought to follow the same first order autoregressive process (37).

The model of (18), (38) and (40) strongly restrict the coefficients of the output, money forecasting and pricing equations. To test whether these restrictions are rejected by the data, one can compare the fit of the model estimated with the restrictions to the fit of less constrained models.

As shown, for instance, in Wilson [1973] the hypothesis that r restrictions are true is acceptable for low values of the statistic, $T[\ell_r - \ell_u]$ where T is the number of observations, ℓ_u is the logarithm of the determinant of the empirical covariance matrix of the errors when the estimation is carried out without the restrictions and ℓ_r is the corresponding quantity when the estimation is carried out imposing the restriction. In particular, under the null hypothesis that the restrictions are true, the quantity $T[\ell_r - \ell_u]$ is distributed $\chi^2(r)$ where r is the number of restrictions.

In Section V, the model of equations (18), (38) and (40) will not only be estimated, but it will also be tested against a variety of alternatives using this technique.

c) The path of the price level when certain prices are exogenous

In the above analysis, all the prices in the economy were assumed to be set by firms with market power who perceived price changes to be costly. However, in the U.S., it is clear that not all prices are set by firms to whom these properties can be attributed. Instead, the above model seems best suited to explain the prices charged by the nonfarm business sector.

The dollar prices of agricultural goods are probably the prices that clear a competitive world market. Even those agricultural goods whose outlets are relatively small (like blueberries) are produced by competitive firms to whom it is hard to attribute a pricing rule like (6). The prices of government services are set with consideration other than profit maximization. Meanwhile the prices of the internationally traded goods are also mostly set in world markets. In this section it will be assumed that the prices of the goods that enter the U.S. GNP, but are not produced by the business non-farm sector, can be grouped in an index whose logarithm is p_o. This index will be assumed to be econometrically exogenous in the sense of Sims [1975]. That is, it will be assumed that this index can best be explained by a univariate time series process. In particular, this index will not be allowed to respond to the history of monetary innovations or even to the prices of the business nonfarm sector. This assumption of econometric exogeneity is tested below and is not rejected by U.S. data.

The demand for the composite good whose price is exp $\{p_o\}$ is assumed to be given by (1). The price level is therefore given by:

$$p_t = \frac{h_o}{\sum_{i=0}^{n} h_i} p_{ot} + \left(1 - \frac{h_o}{\sum_{i=0}^{n} h_i}\right) \bar{p}_t \tag{41}$$

where

$$\bar{p}_t = \left(\sum_{i=1}^{n} h_i p_{it}\right) / \left(\sum_{i=1}^{n} h_i\right) \tag{42}$$

That is, $\bar{p}_t$ is an index of the average price charged by the private non-farm business sector. The log of the price level is a convex combination of $\bar{p}$ and p_o. Letting

$$\omega = h_o / \sum_{i=0}^{n} h_i$$

the path of $\bar{p}$ can be described by:

$$\left(1 - \alpha L - \frac{(1 - D(1 - \omega)}{\beta\rho c(1 - 1/\beta L)}\right)\bar{p}_t = \frac{1}{\beta\rho c} \frac{1}{1 - 1/\beta L}(Dm_t + \omega(1 - D)p_{ot} - S - Dv_t) .$$

$$\bar{p}_t = \gamma\bar{p}_{t-1} + \frac{D}{\delta\rho c} \sum_{j=0}^{\infty} \left(\frac{1}{\delta}\right)^j (m_{t/t+j} - v_{t/t+j} - S/D) + \frac{(1-D)\omega}{\delta\rho c} \sum_{j=0}^{\infty} \left(\frac{1}{\delta}\right)^j p_{ot/t+j} \tag{43}$$

where $\gamma < 1 < \delta$ and

$$\delta + \gamma = 1 + \frac{1}{\rho} + \frac{D}{\rho c} + \frac{\omega(1 - D)}{\rho c}$$

$$\delta\gamma = \frac{1}{\rho}$$

Therefore

$$(\delta - 1)(1 - \gamma) = \frac{D}{\rho c} + \frac{\omega(1 - D)}{\rho c} \tag{44}$$

Therefore, the private nonfarm business price index does not just depend on the future money stocks, but also on the future exogenous component of the price level. This is so because the set of exogenous prices is a determinant of the long run equilibrium private business price index for two reasons. First, the composite good whose price is exogenous is an input into production and an increase in its price will, in the long run, be partially passed on to the consumers. Second, a change in the exogenous price affects the level of real money balances and, hence, aggregate demand. Therefore, it requires a change in $\bar{p}$ in the long run.

Note that the parameters γ and δ are somewhat different from the parameters in the case in which all the prices are set by firms that use rules of like (6). In the normal case in which D is smaller than one, the adjustment of $\bar{p}$ is faster the larger is the component of the price level which is exogenous. This has a simple interpretation. When a large fraction of the prices are exogenous, changes in money balances or in the exogenous prices exert large pressures on the endogenous prices leading them to adjust faster.

Let the exogenous prices be described by

$$\Lambda(L)p_{ot} = \zeta_t \tag{45}$$
$$\Lambda(L) = 1 - \Lambda_1 L - \Lambda_2 L^2 \ldots\ldots\ldots \Lambda_b L^b$$

where the roots of $\Lambda(z) = 0$ are larger than ρ in absolute value and the ζ's are independent normal variates with zero mean and variance σ_ζ^2. Then, using the result of Hansen and Sargent (1980) that was referred to above and letting

$$Z = \frac{D}{\delta\rho c}$$

one obtains:

$$\bar{p}_t = \gamma \bar{p}_{t-1} + \Psi\left(\frac{1}{\delta}\right)^{-1} Z\left[1 + \sum_{j=1}^{k-1}\left(\sum_{i=j+1}^{k}\left(\frac{1}{\delta}\right)^{i-j}\psi_i\right)L^j\right] m_t + (1-\gamma)S$$
$$+\left[\frac{(\delta-1)(1-\gamma)}{\delta} - Z\right]\left[\Lambda\left(\frac{1}{\delta}\right)^{-1}\right]\left[1 + \sum_{j=1}^{n-1}\left(\sum_{i=j+1}^{n}\left(\frac{1}{\delta}\right)^{i-j}\Lambda_i\right)L^j\right] p_{ot}$$
$$+\frac{Z\delta}{\delta-\lambda} v_t \qquad (46)$$

Equation (46) makes the private nonfarm business price index a function of observables only. In particular, lagged values of m and p_o help explain $\bar{p}$ only because they help explain the future values of m and p_o.

Equation (46) imposes strong restrictions across the coefficients of the AR processes for m and p_o and the coefficients of (46). Three behavioral coefficients can be identified. These are z, δ and γ. Note that the coefficient, ω , the weight of the exogenous prices in the price level, is not identified. Even though ω appears in (43), it does not appear in the estimating equation (45) because the constraint (44) has to be imposed on the estimated parameters. Four coefficients enter the private sector's maximization problem. These are ω, D, p, and c. Unfortunately we can only recover three nonlinear functions of these coefficients. Therefore the results of this estimation procedure do not allow one to simulate the response of the economy to a change in ω without some additional information.

IV. Do Relative Prices Follow a Random Walk?

A very important model of asset prices predicts that asset prices ought to follow a martingale. Lucas (1978) and Le Roy (1973) have shown that when consumers are risk neutral and do not discount the future, then the price of assets relative to consumption goods should have

the martingale property. Sims [1980b] showed that this property can be extended to any competitive equilibrium with assets provided that a) markets are complete and b) the time interval analyzed is short. That is, over small time intervals the changes in relative prices ought to be uncorrelated with variables in the current information net. Of course, markets are not complete in the U.S.

However, I think that the Arrow-Debreu model ought to be the benchmark economic model. Therefore, before models in which prices are sticky can be taken seriously, they have to show their superiority over a model in which prices behave as if markets were complete and price changes costless. This is the purpose of testing whether relative prices follow a martingale.

For relative prices to follow a martingale, it would still be necessary that goods be held as assets. Therefore the analysis in this section abstracts from such things as storage costs, transportation costs, etc. These are, of course, important considerations. However, I think that at any point in time there is always some firm which has a warehouse operating under excess capacity. For this particular firm, the shadow price of its warehousing services ought to be zero and it should be willing to speculate in goods.

If the real rate of interest on financial assets were always greater than zero, speculation in goods might be absurd. That is, if financial assets represented claims on a growing amount of goods, then financial assets ought to be preferable to storing a fixed bundle of goods. Then no speculator would be interested in the behavior of relative prices as long as these were not expected to fluctuate by more than the market real

rate of interest. On the other hand the real rate of interest has not been consistently positive in the postwar U.S. In fact, the return in terms of consumer goods of a one month investment in three month treasury bills has been zero on average. The same has been true of the return in terms of consumer goods of an investment for a month in a basket of goods like the one used in the computation of the producer price index.

Therefore, agents ought to speculate in goods as much as they speculate in treasury bills if their objective is to expand the bundle of consumption goods they will be able to afford in the future. And, by Sims' [1980b] argument, relative prices of costlessly storable durable goods ought to follow a random walk.

There is a related argument that also leads relative prices to follow a random walk. Fama [1976] has presented evidence that the expected real return on treasury bills is not significantly different from zero. Therefore, by simple arbitrage the expected real return on goods ought to be always zero. This is just another way of saying that relative prices ought to follow a random walk. Whenever information arrives that alters private agents' perceptions of the future demands and supplies for any given good then its relative price ought to change with the expectation that this new piece of information will not affect future changes in relative prices.

Instead, the model of sticky prices presented in Sections II and III allows neither consumers nor intermediaries to speculate in goods. In the U.S. it turns out to be quite difficult to engage in this type of specula-

tion. I think that this difficulty does not result only from the presence of storage costs. Instead, I think that many of the goods that make up the producer price index can only be bought by regular customers. That is, in these markets, small numbers of sellers are able to eliminate speculation in their goods by selling only to their usual customers. In particular, many of these companies operate through exclusive dealerships.

Of course it is next to impossible to speculate by holding consumer goods, since these are the goods sold by retailers. They can essentially never be resold for a higher price than the purchase price since the latter includes the services performed by the retailer which cannot be resold.

The model of sections II and III is not the only model that makes changes in relative prices be correlated. In particular, Hercowitz (1980) has modified the Lucas islands model to produce serially correlated changes in relative prices. Remember that in the Lucas model the inhabitants of any given island cannot trade with or acquire information about other islands. Since different goods are produced in different islands, no speculation in goods is allowed.

Since relative prices do not follow a trend, as will be shown later, this section will concentrate on whether relative prices follow a random walk, that is on whether: $E_{t-1} r_t = r_{t-1}$, where r_t is a relative price at t.

The relative prices that will be studied are ratios of the prices of consumer good bundles over the prices of bundles of wholesale goods. I will consider two consumer price indices. One is the consumer price index for all items, while the other is the consumer price index for all items except food.

The reason for considering the exclusion of food is that the food sector is fairly competitive. Therefore the model of Sections II and III may not explain the behavior of prices in the food sector very well.[6/] In particular, the relation between the wholesale and the retail prices of food may well follow a random walk.

Three producer price indices will be considered. The producer price index that includes all items will be compared against the cpi that includes all items. Instead, the cpi that does not include food will be contrasted successively with the ppi of prices of intermediate goods that do not include food, with the ppi of prices of crude goods that do not include food and with the ppi of prices of final goods that do not include food. These data are all produced by the Bureau of Labor Statistics.

Notation

ca_t log of the cpi all items not seasonably adusted at t

cnf_t " " " " " " except food " " " " "

wa_t " " " ppi " " " " " " " "

wc_t " " " " crude goods except food " " " " "

wi_t " " " " intermediate " " " " " " " "

wf_t " " " " final " " " " " " " "

I now define the following relative prices of bundles at t:

$$ra_t \equiv ca_t - wa_t \tag{47}$$

$$rcnf_t \equiv cnf_t - wc_t \tag{48}$$

$$rinf_t \equiv cnf_t - wi_t \tag{49}$$

$$rfnf_t \equiv cnf_t - wf_t \tag{50}$$

It is assumed that the shocks that affect prices are lognormal. Therefore the random walk hypothesis would require the variables ra_t, $rcnf_t$ $rinf_r$ and $rfnf_t$ to be equal to their previous value plus a normal iid variate with the zero mean and finite variance.

The first test of the hypothesis that the series given by (47) through (50) follow a random walk is a Box-Pierce test on the differences between the current values of ra, rcnf, rinf and rfnf and the previous values of these series.

This test ascertains whether under the null hypothesis that these series do indeed follow a random walk, the innovations in the series are serially uncorrelated. Evidence that the innovations are correlated is evidence that the random walk is a poor model for the series.

The test on the series ra_t, for instance, requires the computation of the quantity T_{ra} such that:

$$T_{ra} = (N - k - 1) \sum_{i=1}^{k} \left(\frac{\sum_{t=k+1}^{N} (ra_t - ra_{t-1})(ra_{t-i} - ra_{t-1-i})}{\sum_{t=k+1}^{N} (ra_t - ra_{t-1})^2} \right)$$

This quantity ought to be distributed χ^2 with k degrees of freedom as is shown, for instance in Box and Pierce (1968). The critical value of χ^2 statistic with 16 degrees of freedom at the 99.9% confidence interval is 39.3. Instead the values of the above statistics for the series ra, rcnf, rinf and rfnf are much higher, as can be seen from table 1. The statistics are based on 391 monthly observations from 1948:6 to 1980:1. Therefore, the hypothesis that ra, rcnf, rinf and rfnf follow a random walk is rejected by these U.S. data. Note that the hypothesis is closest to being

Table 1

Statistic	Value
T_{ra}	60.45
T_{rcnf}	120.49
T_{rinf}	388.69
T_{rfnf}	150.66

accepted when food is included in both the cpi and the ppi as was expected. The rejection of this hypothesis by the Box-Pierce statistic implies that changes in relative prices are correlated, as predicted by the model presented in this thesis.[7/]

We are not just interested in knowing that the hypothesis that relative prices follow random walks can be rejected, but also in finding out how to predict changes in relative prices. To do this, the following equation was fitted using the variables defined in (47) through (50) as the dependent variable r_t, the relative price at t.

$$r_t = c + a_1 t + a_2 r_{t-1} + a_3(r_{t-1} - r_{t-2}) + a_r(r_{t-2} - r_{t-3}) \qquad (47)$$

The results of these regressions are reported in Tables 2, 3, 4 and 5. For the null hypothesis that r_t follows a random walk to be accepted, c, a_1, a_3 and a_4 must be insignificantly different from zero, while a_2 must be insignificantly different from one. In other words, the autoregressive representation of these series must not only have a unit root ($a_2 = 1$), but it must also not have any other roots. Furthermore, there must be no consistent return to holding one bundle of goods, and this is assured by c and a_1 being equal to zero.

TABLE 2

Dependent Variable ra_t

Regressions \ Explanatory Variables	ra_{t-1}	$ra_{t-1} - ra_{t-2}$	$ra_{t-2} - ra_{t-3}$	t	c	DW	R^2
I	.995 (.004) [-1.489]					1.78	.990
II	.992 (.005) [-1.521]				-2.8E-4 (4.2E-4	1.78	.990
III	.995 (.007) [- .722]			-2.6E-6 (3.3E-6)	4.2E-4 (9.8E-4)	1.79	.990
IV	.993 (.007) [-1.099]	.097* (.051)	.088* (.051)	-1.1E-6 (3.4E-6)	-4.9E-5 (9.9E-4)	2.01	.990
V	.991 (.005) [-1.663]	.099* (.051)	.090* (.051)			2.01	.990

TABLE 3

Dependent Variable $rcnf_t$

Explanatory Variables	$rcnf_{t-1}$	$rcnf_{t-1} - rcnf_{t-2}$	$rcnf_{t-1} - rcnf_{t-3}$	t	c	DW	R^2
Regressions							
I	1.006^{o} (.003) [1.717]					1.29	.990
II	1.005^{o} (.005) [1.021]				1.7E-4 (.001)	1.29	.990
III	1.003^{o} (.005) [.573]			-1.7E-5* (7.2E-6)	.003 (.002)	1.30	.990
IV	.999 (.005) [-.183]	.370** (.051)	-.064 (.051)	-1.3E-5 (6.8E-6)	.002 (.002)	1.96	.991
V	1.001^{o} (.005) [.127]	.376** (.051)	-.059 (.051)		-6.3E-4 (.001)	1.96	.991

TABLE 4

Dependent Variable $rinf_t$

Explanatory Variables	$rinf_{t-1}$	$rinf_{t-1} - rinf_{t-2}$	$rinf_{t-2} - rinf_{t-3}$	t	c	DW	R^2
Regressions							
I	1.000 (.003) [-.071]					.73	.993
II	.998 (.004) [-.417]				2.4E-4 (3.6E-4)	.73	.993
III	1.000 (.004) [-.028]			-3.5E-6 (2.4E-6)	5.4E-4 (6.4E-4)	.74	.994
IV	.994 (.003) [-1.660]	.566** (.051)	.111* (.051)	-4.2E-7 (1.8E-6)	-2.7E-4 (5.0E-4)	2.01	.996
V	.994 (.003) [-1.790]	.566** (.051)	.011* (.051)		3.6E-4 (2.7E-4)	2.01	.996

TABLE 5

Dependent Variable $nfnf_t$

Explanatory Variables	$rfnf_{t-1}$	$rfnf_{t-1} - rfnf_{t-2}$	$rfnf_{t-2} - rfnf_{t-3}$	t	c	DW	R^2
Regressions							
I	.994^{o} (.002) [-3.277]					1.16	.999
II	.996 (.002) [-1.933]				4.3E-4* (1.9E-4)	1.18	.999
III	1.000 (.006) [-.069]			3.5E-6 (4.4E-6)	.001 (.001)	1.19	.999
IV	.993 (.005) [-1.312]	.330** (.051)	.202** (.051)	3.3E-6 (4.0E-6)	6.9E-4 (.001)	2.02	.999
V	.997 (.002) [-1.549]	.327** (.050)	.197** (.050)		1.5E-4 (1.7E-1)	2.02	.999

Notes for Tables 2, 3, 4 and 5.

Standard errors are in parentheses; figures in brackets are the t-statistics about 1.

* Significantly different from zero with 95% confidence

** Significantly different from zero with 99% confidence

o Significantly different from one with 95% confidence using Fuller's ( ) table.

To test whether a_2 is different from one, I compute the t-statistic of the coefficient of the lagged dependent variable around one. However, this statistic should not be compared with Student's t distribution. Dickey and Fuller [1979] have shown that the standard t-test is assymptotically invalid under the null hypothesis that a_2 is equal to one. Instead, Fuller [1976] provides a table of the empirical distribution of the t-statistic under the null hypothesis. Using this table, one can ascertain that all series, except possibly rcnf, have a unit root. Furthermore, the coefficients c and a_1 are insignificantly different from zero for all the series. However, the coefficients a_3 and a_4 are significantly different from zero with 99 percent confidence in most cases. The current change in relative prices can be predicted by past changes in relative prices.

Therefore, the autoregressive representation of these series of relative prices have a unit root in addition to other nonzero roots. The presence of these latter roots rejects the hypothesis that relative prices follow a random walk.

When one couples this result with Fama's (1976) which states that real rates of return on treasury bills are always predicted to be equal to zero then one must conclude that goods are, at least some of the time, an investment superior to T-bills.

To sum up, the data on relative prices reject a model in which there are no distortions in the goods market. It does not necessarily favor the hypothesis that the distortions are of the type that are analyzed in this thesis. Using aggregate data one can test some more specfic implications of the model.

V. Estimation and Testing of the Model using Aggregate Data

A. Generalities

To estimate the aggregate model of Sections II and III, it is first necessary to decide which observable variables best represent the theoretical constructs m, p and q. The model of this thesis does not allow for growth. That is, the supply of factors is assumed fixed, in order to focus on the cyclical fluctuations of output about its trend.

The empirical counterpart of this model also focuses on the fluctuations of the various variables about their trends. Therefore, all the variables were detrended. Furthermore, their mean was removed in the same process. Therefore, all the equations will be estimated without constant terms. The resulting series, as well as the techniques employed to derive them, are presented in the appendix. The money stock that enters into the demand function (1) is assumed to be M1. The index of aggregate output Q is assumed to behave like GNP even though Q is supposed to include all the outputs of intermediate goods sections. The price level is represented successively by the cpi and by the GDP deflator. [7/] The variable p_o, the index of the prices that are assumed to be exogenous, is a weighted average of the prices of the sectors other than the private nonfarm business sector. The weights are given by the proportion of these sectors in total GDP. For the purpose of estimation, all variables are in natural logarithms as predicted by the theory.

Before estimating the model, one question must be addressed. What equation ought to be used by both the rational agents and by econometricians when forecasting m and p_o, the variables which are not under the control of

price setting firms? Here, it is postulated that the best forecasting equations are given by parsimonious univariate autoregressions like (36) and (45). However, if the endogenous variables helped to predict m and p_o, rational firms would employ them for this purpose. Therefore, subsection B is devoted to checking that, indeed, the endogenous variables do not significantly help in predicting m and p_o. Then, it proceeds to present the parsimonious autoregressions which are taken to be the forecasting equations used by rational agents in the U.S.

In subsequent sections, the model is estimated in two versions. First, in subsection C, all prices are assumed to be set by firms with loss function (4). Second, in subsection D, only those firms that produce nonfarm output are assumed to have the loss function (4). The other prices, aggregated in p_o, are assumed to be exogenous. The estimates of these sections are the result of estimation via maximum likelihood. The DFP and MINOPT algorithms were used to obtain convergence.

B. The prediction of m and p_o

This section begins by presenting evidence suggesting that the univariate representation (36) for m and (45) for p_o are indeed appropriate descriptions of these series. These equations are, therefore, likely to be the equations used by firms when forecasting m and p_o.

The firms in this economy are trying to predict the future values of m and p_o using all available current information. Therefore, they would use as predictors any lagged values of the other endogenous variables if these values helped perdict m and p_o. By the definition of Granger causality, the endogenous variables are not useful predictors of m and p_o if and only

if they do not cause m and p_o. A variable, x, is said to cause y in the Granger [1969] sense if the variance of y about the expectation of y conditional on past values of y alone is significantly larger than the variance of y about the expectation conditional on past values of y and past values of x. Numerous techniques to test the null hypothesis of absence of causality in the Granger sense have been proposed. Pearce and Haugh [1977] provide a survey of these techniques. The simplest one has been used by Sargent [1976] and has been proposed in the original paper by Granger [1969].[8/] It consists of regressing the variable y on its own past and on the past of x. An F-test can be computed to determine whether the lagged values of x contribute significantly to the forecast of y. To ensure that causality is not found when it is not really present, enough lagged values of y must be included. Furthermore, for the F-test to be precise, it is important that the residuals of the regression of y on its own past and on the past of x be serially uncorrelated.

The question of whether money is caused or causes GNP has received wide attention in recent years (see, for instance, the studies by Sims [1972, 1980], Feige and Pearce [1974], Sargent (1976]). In general, these studies have concluded that in the postwar U.S. money causes but is not caused by national income.

Tests of the null hypothesis that the variables m and p_o that will be used to estimate the model of Sections II and III are exogenous are presented in Table 6. The hypothesis that the money stock is exogenous is tested both with seasonally adjusted data (m) and with data that have not been seasonally adjusted ($\hat{m}$).

Ninety-five percent of the mass of an F distribution with 5 and 125

degrees of freedom is below the value 2.29. The null hypothesis that x does not cause y cannot be rejected with 95 percent confidence if the F-statistic that results from comparing all the estimated β_j's with zero is below 2.29. Therefore, this hypothesis can be rejected for none of the combinations of X and Y in Table 6. In particular, neither the seasonally adjusted nor the not seasonally unadjusted money stock is caused by either the price level (measured by the cpi) or aggregate output. Furthermore, the seasonally adjusted money stock is not caused by either of the two components of the price level which will be studied separately below. These components are the private nonfarm business price index and the index of all other prices which enter GNP which is called $\dot{p}_o$.

Finally, the index p_o appears not be caused by income nor by the private nonfarm business price index nor by the money stock.

Next, the parsimonious representations of (36) and (45) for m and p_o must be found. The OLS regressions that are the result of fitting these representations must have the following properties. First, the residuals of these regressions must appear to be white noise. Second, the inclusion of other lags of the dependent variable on the RHS must not significantly reduce the sum of squared residuals of these regressions. The parsimonious representations were obtained by studying the series by the methods suggested by Box and Jenkins [1970].

The series m can be parsimoniously represented by an AR(2) process of the first difference of m. In other words, (36) becomes:[8/]

$$(1 - \bar{\psi}_1 L - \bar{\psi}_2 L^2)(m_t - m_{t-1}) = \xi_t \qquad (51)$$

The OLS estimates of eq. (51) are given by:

Table 6

Tests of Causality from X to Y

Regressions of Y_t on $\sum_{i=1}^{3} \alpha_i Y_{t-i} + \sum_{j=1}^{5} \beta X_{t-j}$

Time Period	Y	X	α_1	α_2	α_3	β_1	β_2	β_3	β_4	β_5	DW	R^2	F-statistic all $\beta_j = 0$	SSR	
48II-79II	m	y	1.53	-.64	.08	.07	-.10	.03	-.003	.03	1.92	.97	.731	2.895	E-3
			(.10)	(.18)	(.11)	(.05)	(.08)	(.08)	(.08)	(.05)					
48II-79II	m	p	1.59	-.69	.07	-.06	-.02	.26	-.23	.05	1.90	.97	.836	2.883	E-3
			(.10)	(.18)	(.10)	(.09)	(.16)	(.17)	(.16)	(.08)					
48II-79II	m	p_o	1.61	-.78	.15	.01	.01	-.05	.08	-.05	1.89	.97	1.769	2.781	E-3
			(.09)	(.17)	(.10)	(.02)	(.03)	(.03)	(.03)	(.02)					
48II-79II	m	$\bar{p}$	1.59	-.71	.10	-.12	.17	-.03	-.06	.03	1.90	.97	.523	2.919	E-3
			(.10)	(.18)	(.10)	(.08)	(.13)	(.13)	(.13)	(.08)					
48II-79II	m	-	1.58	-.70	.09						1.91	.97		2.981	E-3
			(.09)	(.17)	(.10)										
49II-79II	$\hat{m}$	y	1.36	-.63	.06	.07	-.01	-.06	-.08	.10	1.96	.86	.957	5.051	E-3
			(.10)	(.16)	(.10	(.07)	(.10)	(.10)	(.10)	(.06)					
49II-79II	$\hat{m}$	$\hat{p}$	1.44	-.64	.03	-.14	.08	.29	-.30	.08	2.01	.86	2.274	4.806	E-3
			(.09)	(.15)	(.10)	(.09)	(.14)	(.14)	(.14)	(.08)					
49II-79II	$\hat{m}$	-	1.42	-.65	.05						1.97	.85		5.243	E-3
			(.09)	(.16)	(.09)										
48II-79II	p_o	y	1.01	-.11	-.11	.32	-.20	-.24	-.23	-.03	2.01	.74	1.049	4.127	E-2
			(.09)	(.14)	(.10)	(.19)	(.31)	(.30)	(.29)	(.17)					
48II-79II	p_o	m	.93	-.07	-.13	.07	.37	-.38	.33	-.28	2.02	.74	1.693	4.026	E-2
			(.09)	(.12)	(.09)	(.36)	(.71)	(.78)	(.72)	(.37)					
48II-79II	p_o	$\bar{p}$	.97	-.13	-.08	.43	-.40	.33	-.96	.59	1.99	.74	1.421	4.068	E-2
			(.09)	(.13)	(.09)	(.31)	(.50)	(.50)	(.50)	(.29)					
48II-79II	p_o	-	.99	-.08	-.14						2.03	.73		4.306	E-2
			(.09)	(.12)	(.08)										

Notes: These regressions were performed on quarterly data.

Standard errors are in parentheses.

The variables with a hat are fourth differences of data that have not been seasonally adjusted. For instance $\hat{m}_t$ is the log of the money stock not seasonally adjusted at t minus the log of the money stock not seasonally adjusted at t-4. Variables without a hat refer to seasonally adjusted data.

$$m_t - m_{t-1} = \underset{(.09)}{0.62}\,(m_{t-1} - m_{t-2}) - \underset{(.10)}{0.13}(m_{t-2} - m_{t-3}) + \zeta_t$$

DW: 1.92 R^2: .308 Period: 1948I to 1979II

where the standard errors are in parentheses.

The seasonally unadjusted money stock $\hat{m}$ can be parsimoniously represented as on AR(2) process of the fourth difference of $\hat{m}$. Eq. (36) therefore becomes: [9/]

$$(1 - \hat{\psi}_1 L - \hat{\psi}_2 L^2)(m_t - m_{t-4}) = \xi_t \qquad (52)$$

The OLS regression that encompasses this representation is given by:

$$\hat{m}_t - \hat{m}_{t-4} = \underset{(.07)}{1.38}\,(\hat{m}_{t-1} - \hat{m}_{t-5}) - \underset{(.07)}{0.56}\,(\hat{m}_{t-2} - \hat{m}_{t-6}) + \zeta_t$$

DW: 1.93 R^2: .854 Period: 1948III to 1979II

where the standard errors are in parentheses.[10/]

Finally, the process followed by p_o can also be represented parsimoniously as an AR(2). Equation (45), therefore, becomes:

$$(1 - \Lambda_1 L - \Lambda_2 L^2)p_{ot} = \zeta_t \qquad (53)$$

The OLS estimates of (53) are given by:

$$p_{ot} = \underset{(.087)}{1.057}\,p_{ot-1} - \underset{(.087)}{.267}\,p_{ot-2}$$

DW: 2.05 R^2: .710 Period 1948I to 1979II

C. All price are endogenous

In this section I will estimate the system composed of the money forecasting equation (36), the price level equation (40), the output

equation (18) and the equation that gives the evolution of the taste for money balances over time (37). These equations are repeated here without constant terms, just as they will be estimated, for easy reference.

$$\psi(L)m_t = \xi_t \tag{36}$$

$$p_t = p_{t-1} + \frac{(\delta-1)(1-\gamma)}{\delta} \Psi \left(\frac{1}{\delta}\right)^{-1} \left[1 + \sum_{j=1}^{k-1} \sum_{i=j+1}^{k} \left(\frac{1}{\delta}\right)^{i-j} \psi_i \cdot L^j\right] m_t + \left[\frac{(\delta-1)(1-\gamma)}{\delta - \lambda}\right] v_t \tag{40'}$$

$$y_t = d\,(m_t - p_t - v_t) \tag{18'}$$

$$v_t = \lambda v_{t-1} + \nu_t \tag{37}$$

It is possible to estimate consistently the parameters γ and δ, the roots of the characteristic function that describe the evolution of the price level, by fitting (40') all by itself. This can be done by using the values obtained from the OLS regressions of (51) and (52) for the Ψ_i in (40'). However, this procedure is not as efficient as the joint estimation of (36) and (40') in which the cross equation restrictions are imposed.

Similarly, the parameter λ can be estimated consistently by fitting either (40') or (18') by themselves after applying the transformation due to Koyck. However, the estimates of λ that result from the simultaneous estimation of these two equations is more efficient. On the other hand, if output were also influenced by an excluded serially correlated variable,

one would not expect the coefficient that gives the serial correlation of the errors of the output equation to be the same as the corresponding coefficient of the price equation. Since a weighted average of relative prices which could be serially correlated and time varying is assumed to be constant in order to derive (18), the output equation might well be plagued by the inclusion of a relevant serially correlated variable.

If this problem were present, then the estimation of (18') and (40') jointly would lead the misspecification of the output equation to pollute the estimates of the parameters of the price equation. This would be true whether one imposed the restrictions that the estimated λ's be the same or not. The model was thus estimated in three versions. First, it was estimated without the output equation (Specifications I and II). Then it was fitted including the output equation and imposing the cross equation restriction on the estimate of λ (Specification III). Finally, (18') and (40') were estimated jointly, but λ_1, the estimate of λ from the price equation, was allowed to be different from λ_2, the estimate of λ from the output equation (Specification IV).

Note that the coefficient, λ, is quite important. Those that believe that shifts in tastes (or in Keynes's words, shifts in animal spirits) do not affect aggregate output significantly but feel instead the business cycles are caused exclusively by variations in m, would not expect the unobserved variable, v, to play an important role. Instead, those that believe that nominal taste shocks are recurrent and that their influence ought to be dampened through the use of stabilizing aggregate demand policies, would expect v to be an important determinant of the price level and output. This debate lends the coefficient, λ, its importance. If λ is different from zero, then the errors in the price equation (40) are

partly responsible for the fact that the deviations of output from trend are serially correlated. By interpreting this error as a nominal shock that is due to tastes, one can then conclude that shifts in tastes are partly responsible for the "cyclic" nature of y. Instead, if λ is equal to zero, then all the "cyclic" properties of y can be attributed to changes in the money stock.

To ascertain the consequences of forcing λ to be zero, the price equation was fitted both with (Specification II) and without (Specification I) correction for serial correlation of the errors.

The model also imposes three inequality restrictions on the parameters γ, δ and d which, for computational convenience, were not imposed in the estimation. The roots γ and δ of the equation that characterizes prices must have the property that $\gamma < 1$ while $\delta > 1$. Furthermore, the coefficient, d, which measures the elasticity of aggregate output with respect to money balances, must be positive. These inequalities can, of course, be tested one by one using the estimates of the standard errors of the coefficients.

One issue which must be addressed is whether the data ought to be seasonally adjusted or not. Using seasonally unadjusted data would be warranted if the seasonal pattern in prices is due to the seasonal pattern of the exogenous variables (in this case money and v) together with the model. Instead, the use of seasonally adjusted data would be required if the seasonal pattern in prices and output were due to other causes like the weather, the proximity of Christmas, and so forth.

The estimation was carried out using both seasonally unadjusted and seasonally adjusted data for the price level and the money stock.

The estimates of the coefficients using the seasonally adjusted money stock as the primary influence on the seasonally adjusted cpi and on the GDP deflator are presented respectively in Tables 7 and 8. Table 9 presents the estimates that result from using the seasonally unadjusted M1 and cpi.

The results for the seasonally adjusted cpi are virtually identical to those for the GDP deflator. In many ways the GDP deflator is the more natural variable to focus on since it includes all the prices that enter the index of aggregate output y. The cpi was used in order to contrast the estimation using seasonally unadjusted data with the estimation using data that were previously seasonally adjusted. Furthermore the cpi has the advantage of having fixed weights as does the price index for which the model generates predictions. Instead, the weights of the GDP deflator are current period weights.

The Walrasian equilibrium of this model would be observed if γ were equal to zero and δ equal to infinity. This would, of course, require that the only explanator of the price level be the contemporaneous level of money balances. Such a hypothesis is rejected by all the estimating equations, thereby lending credibility to the notion that prices are sticky in the U.S. Furthermore, the adjustment of prices is shown to be very slow. This is evidenced by the high values of γ, the coefficient of lagged prices in the price equation.

This slowness is due to one of two causes: either the effect of real money balances on demand is small enough to cause penalties that accrue from charging the wrong prices minimal, or the subjective costs of charging prices are high. This can be seen by computing the underlying

Table 7

Estimation of the model to explain the path of the seasonally adjusted cpi
Quarterly Data 1948 I to 1972 II

	Specification			
	Price and Money Eqs.		Price, Money and Output Eqs.	
Coefficients	I	II	III	IV
$\bar{\Psi}_1$	.621 (.092)	.628 (.094)	.562 (.089)	.570 (.091)
$\bar{\Psi}_2$	-.135 (.099)	-.144 (.100)	-.105 (.113)	-.115 (.115)
γ	.966 (.017)	.928 (.046)	.739 (.072)	.720 (.084)
δ	780.884 (.126)	2140.600 (.126)	.893 (.348)	.879 (.299)
λ_1		.717 (.078)	.916 (.030)	.931 (.046)
λ_2				.913 (.029)
d			.431 (.155)	.453 (.163)
Single Equation Statistics				
R^2_M	.308	.308	.306	.307
DW_M	1.922	1.933	1.823	1.834
R^2_p	.973	.986	.984	.984
DW_p	.614	2.061	1.950	1.941
R^2_y			.905	.906
DW_y			1.261	1.258
Global Statistic				
ℓ	-20.4705	-21.1533	-30.4234	-30.4245

Notes for Tables 7 - 9: Assymptotic standard errors are in parentheses. The subscript M refers to a single equation statistic corresponding to the money forecasting equation. Similarly, the subscripts p and y refer to statistics corresponding to the pricing and the output equations respectively. The statistic ℓ is the logarithm of the determinant of the empirical covariance matrix of the residuals.

Table 8

Estimation of the model to explain the path of the GDP deflator
Quarterly Data 1948 I to 1979 II

	Specification			
	Price and Money Eqs.		Price, Money and Output Eqs.	
Coefficients	I	II	III	IV
$\bar{\Psi}_1$	.619	.623	.548	.551
	(.092)	(.092)	(.081)	(.081)
$\bar{\Psi}_2$	-.132	-.137	.041	.048
	(.097)	(.097)	(.038)	(.043)
γ	.946	.920	.486	.458
	(.016)	.032	(.085)	(.089)
δ	780.884	2140.600	.868	.889
	(.126)	(60.945)	(.072)	(.073)
λ_1		.556	.903	.916
		(.078)	(.024)	(.027)
λ_2				.888
				(.030)
d			.806	.898
			(.199)	(.030)
Single Equation Statistics				
R^2_M	.308	.308	.290	.288
DW_M	1.920	1.925	1.818	1.823
R^2_P	.974	.983	.943	.939
DW_P	.903	2.194	1.794	1.799
R^2_y			.892	.888
DW_y			1.258	1.248
Global Statistic				
ℓ	-20.8178	-21.2103	-30.4641	30.4686

Table 9

Estimation of the model to explain the path of the seasonally unadjusted cpi

Quarterly Data 1948 III to 1979 II

	Specification			
	Price and Money Eqs.		Price, Money and Output Eqs.	
Coefficients	I	II	III	IV
$\hat{\Psi}_1$	1.381	1.377	.816	1.235
	(.071)	(.071)	(.045)	(.075)
$\hat{\Psi}_2$	-.565	-.563	-.005	-.464
	(.071)	(.071)	(.028)	(.071)
γ	.978	.967	.629	.966
	(.017)	(.035)	(.075)	(.032)
δ	2.725	4.820	1.149	2.512
	(.666)	(8.233)	(.115)	(2.341)
λ_1		.628	.938	.614
		(.079)	(.025)	(.077)
λ_2				.919
				(.034)
d			-.059	.201
			(.074)	(.322)
Single Equation Statistics				
R^2_M	.974	.983	.981	.983
DW_M	.783	1.928	1.605	1.898
R^2_p	.854	.854	.879	.848
DW_p	1.923	1.914	1.157	1.608
R^2_y			.774	.886
DW_y			.890	1.176
Global Statistic				
ℓ	-19.9573	-20.4128	-29.3746	-29.6366

behavioral parameters ρ and D/C from (15) and (16).

$$\rho = \frac{1}{\delta\gamma}$$

$$D/C = \frac{(\delta-1)(1-\gamma)}{\delta\gamma}$$

where ρ is the monopolist's discount factor,[11/] D captures the pressure of real money balances on demand, and c measures the costs of changing prices.

The estimates for D/C are indeed very low as required for the prices to move slowly. They are .08 and .09 for the seasonally adjusted and seasonally unadjusted data respectively when using Specification II, the preferred specification which estimates (36), (37) and (40) simultaneously without forcing λ to be zero. This specification is preferred for two reasons: First, it is superior to Specification I which requires λ to be zero. The hypothesis that λ is indeed zero can be tested by comparing the ℓ statistics of the two specifications. It is rejected by the three data sets. This fact suggests that nominal taste shocks are an important determinant of the fluctuations of real money balances and hence of output.

Second, the output equation does appear to be misspecified and, therefore, its separate estimation is warranted since then, at least, the parameters of the price equation will be consistently estimated. The first sign of this misspecification is that the DW statistics corresponding to the output equation are quite low. Furthermore, the hypothesis that the estimate of λ from the price equation λ_1 is the same as the corresponding estimate for the output equation λ_2 is rejected by the seasonally adjusted data as can be seen by comparing the ℓ statistics corresponding to Specifications III and IV.

That the potential misspecification of the output equation affects the joint estimates of the system can be seen by noting that the estimates for δ are below unity when the output equation is included and the data are seasonally adjusted. This runs counter to the model's prediction that the "unstable" root δ be larger than unity. Note that when the output equation is excluded, the estimates for δ are always larger than one. Moreover the joint estimation of the output and price equations with seasonally adjusted data leads to a lower R^2 for both equations than the one obtained from their separate estimation. This is shown by the following estimates obtained by CORC:

$$y_t = \underset{(.109)}{.516}\ (m_t - p_t)$$

$\lambda = .913 \quad R^2 = .906 \quad DW = 1.26 \quad$ Period 1948I to 1979II

where p_t is the log of the detrended cpi at t. The maximum likelihood procedure is worsening the fit of the individual price and output equations in order to increase the covariance of the errors of these equations.

At any rate, the estimate for d, the elasticity of output with respect to money balances, is much smaller than one. Recall that the simple-minded quantity then predicts that d is equal to one.

I now proceed to test these regressions against alternative hypotheses which impose less structure on the data. These less-restricted specifications could arise if either the model of firm behavior was true and the expectations were not computed rationally, or if the expectations were computed rationally but firms chose their prices by pursuing different objectives.

The models estimated in Tables 7 to 9 have many more explanatory

variables than coefficients. For example, when seasonally adjusted data were used, the pricing equation in the first column has four explanatory variables (lagged prices, current and two lags of money), while the money forecasting equation has two explanatory variables. However, only four coefficients are estimated (γ, δ, ψ_1 and ψ_2). Therefore, the model imposes two nonlinear restrictions on the coefficients of six explanatory variables. It is natural to test these cross equation restrictions by comparing each specification to a specification that uses the same explanatory variables but does not restrict the coefficients. The logarithm of the determinant of the covariance matrix of the errors of these unrestricted regressions is ℓ_o. The tests are carried out by computing the quantities $T[\ell_o - \ell]$ and contrasting them with the χ^2 distribution with r degrees of freedom. Here r is the difference in the number of coefficients used in the computations of ℓ_o and the number of coefficients used in the computation of ℓ.

As can be seen in Table 10, the unrestricted estimates using seasonally adjusted data do not reject the model. But, the estimates using seasonally nonadjusted data do reject the model with 99 percent confidence. This leads to the conclusion that prices do have a seasonal pattern of their own, independent of money balances. In other words, the model, together with the movement of m, is able to explain only the nonseasonal component of prices. Instead, the seasonal component must be explained by other hypotheses.

Next, the fit of these specifications which include the output equation is compared with the fit of an even less restricted hypothesis which allows output to be explained by two lags of output as well as by

the current and lagged real money balances. This was done because the output equation may well be misspecified by the exclusion of a serially correlated variable. The logarithm of the determinant of the covariance of the errors from estimating this more unrestricted model is ℓ_1. Indeed, the hypothesis that each explanatory variable has its own coefficient and that output is explained by two lags and current and lagged real money balances, rejects the model when the output equation is estimated jointly with the other equations. This represents further evidence that the output equation is misspecified.

Finally, I contrast the system composed of (36), (37), (18') and (40'), with an extremely unconstrained model, namely a fourth order vector autoregression. The purpose of this comparison is to allow the model to be rejected by models which, while theoretically eclectic, appear to fit the data very well. The vector autoregression is obtained by explaining each variable with four lags of itself and of the other relevant variables. In addition, the errors in the different equations are allowed to be correlated so that the likelihood of the model is proportional to the determinant of the empirical covariance matrix of the errors. Rather than estimating this covariance matrix by FIML, it is simpler to compute the determinant of the matrix that results from first making the error in the different equations orthogonal as is done in Sims [1980a]. To make these errors orthogonal, it suffices to include the current money stock as an explanator of current prices while allowing both the current money stock and current prices to explain current output. Since the errors in the three equations will now be orthogonal, they can efficiently be estimated by OLS. Then, one obtains ℓ_2 as the sum of the logarithms of the sum of

Table 10

Tests of the model when all prices are endogenous

Specification[o]	$T[\ell_o - \ell]$	$T[\ell_1 - \ell]$	$T[\ell_2 - \ell]$
7 I	6.842* [2]		101.455 [12]
7 II	2.289* [3]		15.422* [10]
7 III	4.460* [5]	28.564 [6]	79.393 [30]
7 IV	4.322* [4]	28.426 [5]	79.254 [29]
8 I	5.494* [2]		62.572 [12]
8 II	1.600* [3]		13.117* [11]
8 III	3.931* [5]	23.197 [6]	68.645 [30]
8 IV	3.364* [4]	22.630 [5]	68.072 [29]
9 I	16.331 [5]		109.951 [20]
9 II	25.222 [6]		53.469 [19]
9 III	59.557 [8]	44.705 [8]	184.190 [18]
9 IV	27.069 [7]	36.616 [7]	151.702 [47]

Notes: o The specification number is the number of the table in which the results of this specification can be found followed by the number of the particular specification within the table, i.e., specification 7 IV corresponds to the regression IV of table 7. The numbers in brackets are the numbers of restrictions tested and hence the number of degrees of freedom of the relevant χ^2 distribution.

* The value of the statistic is lower than the value to the left of which lies 99% of the relevant χ^2 distribution.

squared errors of the residuals of the three equations.

As can be seen in Table 10, when seasonally adjusted data are used, the versions of the model in which the output equation is excluded are not rejected by the vector autoregressions. Instead, as would be expected after comparing ℓ_1 with ℓ, when the output equation is included, the vector autoregression with four lags rejects the model with 99 percent confidence.

This section leads to three main conclusions. First, prices do appear to be sticky in the U.S. Second, there is a seasonal component of prices (and hence demand) that is not captured by the seasonal pattern of money balances. Finally, the restrictions on the paths of the price level and money balances implied by the model are not rejected by U.S. data.

C. Some Prices are Exogenous

In this section, $\bar{p}_t$, the deflator for the product of the business nonfarm sector, is assumed to be the result of prices charged by monopolies which face costs of price adjustment. The rest of the prices are assumed to be exogenous and follow (51). The model as it will be estimated, that is, including the restrictions satisfied by the parsimonious representation of the processes characterizing m and p_o, is given by:

$$m_t - m_{t-1} = \bar{\psi}_1(m_{t-1} - m_{t-2}) + \bar{\psi}_2(m_{t-2} - m_{t-3}) + \xi_t \qquad (51)$$

$$p_{ot} = \Lambda_1 p_{ot-1} + \Lambda_2 p_{ot-2} + \zeta_t \qquad (52)$$

$$\bar{p}_t = \gamma \bar{p}_{t-1} + \frac{D}{pc(\delta-1)(1-\psi_1/\delta - \psi_2/\delta^2)} \left[m_t + \left(\frac{\bar{\psi}_2-\bar{\psi}_1}{\delta} - \frac{\bar{\psi}_2}{\delta^2} \right) m_{t-1} - \right.$$

$$- \frac{\bar{\psi}_2}{\delta} m_{t-2}] + \frac{(\delta-1)(1-\gamma) - D/pc}{\delta - \Lambda_1 - \Lambda_2/\delta} (p_{ot} + \frac{\Lambda_2}{\delta} p_{ot-1}) + \frac{D/pc}{\delta - \lambda} v_t \quad (46')$$

$$q_t = d(m_t - p_t - v_t) \quad (18')$$

$$v_t = \lambda v_{t-1} + \nu_t \quad (37)$$

Naturally in (18') the level of money balances must be deflated by a price level that includes both p_o and $\bar{p}$ to yield m's effect on the demands for goods. In particular, in deriving the pricing equation (46), it was assumed that the relevant price level must satisfy:

$$p_t = \omega p_{ot} + (1 - \omega)\bar{p}_t \quad (54)$$

However, as discussed in Section III, the parameter ω is not identified from the estimation of (46). In other words, the estimates obtained from the pricing equations are consistent with any ω.

On the other hand, the logarithm of the GDP deflator cannot be written as a convex combination of p_o and $\bar{p}$ with constant weights. This is due to two reasons. First, the proportion of GDP accounted for by the business nonfarm sector has been increasing steadily in the postwar period. It went from .80 in 1948 to .84 in 1979. Furthermore, a regression of this fraction on a time trend yields a coefficient on the time trend whose t statistic about zero is 20.8. Second, the projections of the logarithms of p_o and $\bar{p}$ on the time trend and the square time trend do not yield identical coefficients. Therefore, even if the fraction of GDP accounted for by the business nonfarm sector were constant, any construct like (54)

would have serially correlated errors.

If the "correct" deflator of money balances is the GDP deflator, then, of course, the pricing equation will have measurement error problems due to the assumption that the relevant price level satisfies (54) for some ω.

On the other hand, the estimation of the output equation would be straightforward since it could suffice to deflate m_t by the detrended logarithm of the GDP deflator to capture the effect of real money balances on output.

If, instead, the "correct" deflator satisfies (54) for some ω, then the pricing equation will be correctly specified while the relevant output equation will be:

$$y_t = d(m_t - \omega p_{ot} - (1 - \omega)\bar{p}_t) + v_t \qquad (55)$$

And, the parameter ω, the weight of the exogenous prices in the price index used by individuals in their decisions to consume, is identified by the output equation.

Six versions of the model were therefore fitted to U.S. data. Since the output equation may be misspecified, it was fitted separately in specification I and II to avoid the potential pollution of the estimated parameters of the other equations. Specification I explores the effects of forcing λ to be zero, while Specification II relaxes this constraint. Specifications III and IV use the GDP deflator as the price index which households take into account when computing this real money balance. Instead, specifications V and VI force that price index to be a convex combination of p_o and $\bar{p}$, as in (54). Finally, while specification III

Table 11

Estimation and testing of the model that explains the private nonfarm business sector's price deflator
Quarterly Data 1948 I to 1979 II

	Specification					
	Price and Money Eqs. / Price, Money and Output Equations					
Coefficients	I	II	III	IV	V	VI
$\bar{\Psi}_1$	.620 (.094)	.619 (.095)	.547 (.110)	.615 (.096)	.595 (.105)	.616 (.098)
$\bar{\Psi}_2$	-.117 (.101)	-.115 (.102)	-.154 (.096)	-.129 (.103)	-.134 (.101)	-.125 (.105)
Λ_1	1.050 (.089)	1.003 (.068)	1.102 (.066)	1.082 (.087)	1.107 (.078)	1.039 (.084)
Λ_2	-.265 (.088)	-.276 (.065)	-.269 (.066)	-.313 (.090)	-.342 (.080)	-.289 (.082)
γ	.968 (.015)	.927 (.039)	.681 (.089)	.956 (.026)	.630 (.096)	.942 (.030)
δ	50.006 (.126)	29.964 (.127)	20.312 (.128)	20.296 (.126)	20.297 (.144)	20.294 (.127)
D/pc	3.140 (1.194)	2.331 (1.384)	5.045 (2.755)	1.615 (.787)	2.573 (3.369)	1.941 (.858)
λ_1		.654 (.065)	.900 (.032)	.503 (.082)	.924 (.034)	.546 (.084)
λ_2				.908 (.036)		.911 (.032)
d			.246 (.229)	.529 (.199)	.364 (.199)	.485 (.210)
ω					-.495 (.464)	-.298 (.318)
Single Equation Statistics						
R_M^2	.308	.308	.301	.308	.308	.308
DW_M	1.923	1.923	1.775	1.912	1.875	1.915
R_o^2	.715	.712	.713	.714	.713	.714
DW_o	2.071	1.964	2.176	2.155	2.212	2.055
R_p^2	.978	.973	.968	.984	.983	.983
DW_p	.996	2.271	2.333	2.313	2.467	2.163
R_y^2			.896	.900	.879	.885
DW_y			1.214	1.274	1.624	1.569
Global Statistics						
ℓ	-28.5672	-28.8997	-38.0891	-38.1533	-38.1425	-38.1551
$T[\ell_o - \ell]$	9.425* [3]	6.413* [5]	13.117* [7]	5.027* [6]	38.090 [10]	35.051 [9]
$T[\ell_1 - \ell]$			44.705 [8]	36.616 [7]	55.742 [11]	54.155 [10]
$T[\ell_2 - \ell]$	90.317 [29]	48.422** [28]	148.138 [55]	140.049 [54]	141.410 [54]	138.822 [53]

Notes: Standard errors are in parentheses. Numbers in brackets are the relevant degrees of freedom for the null hypothesis that the estimates satisfy the constraints imposed by the model. The statistics R_o^2 and DW_o are the R^2 and DW statistics for the equation which makes p_o a function of lagged p_o's.

* The value of the statistics is lower than the value to the left of which lies 99% of the relevant χ^2 distribution.

** The critical value for the $\chi^2(28)$ is 48.2. Therefore, the null hypothesis is almost not rejected with 99% confidence.

and V force the estimate of λ to be the same across the price and output equations, specifications IV and VI relax this requirement on the grounds that the output equation may be misspecified.

Table 11 presents both the estimates corresponding to the various versions of the model and the statistics that can be used to judge their acceptability.

For all the versions, the estimates satisfy those inequality restrictions which the model implies but which were not imposed during the estimation. In particular, γ is positive and smaller than one, δ is greater than one, Z and d are positive. Further, the hypothesis that there are no costs to changing prices is rejected. Moreover, prices are very "sticky" and adjust slowly as evidenced by the high values of γ. These are caused either by a small effect of real money balances on demand (low D) or by high costs of changing prices, c. Indeed, the point estimates of D/C are around .2.[12/]

Once again the parameter λ is significantly different from zero. Furthermore, the hypothesis that the parameter λ is the same in both the price and output equations is not rejected in either of the specifications of the output equation. These facts lend credence to the notion that changes in tastes are responsible for the cyclic movements of output.

The output equations continue to suffer from potential misspecification. Both of its versions have low DW statistics. It is true that the version that uses (18') as the output equation by assuming that the GDP deflator is a good proxy for p is not rejected by a model that uses the same explanatory variables without constraining their coefficients as evidenced by the low values of $T[\ell_o - \ell]$ for specifications III and IV. On

the other hand, all versions of the version of the model which include the output equations are rejected by models which add a second lag of output as an explanator of output as evidenced by the high values of $T[\ell_o - \ell]$. They are also rejected by fourth order vector autoregressions as the high values of $T[\ell_2 - \ell]$ for specifications III through VI indicate.

Another unfortunate feature of the output equation is that when (55) is fitted jointly with the other equations, it leads to an estimate for ω which has the wrong sign and a large standard error. However, this estimate is not significantly different from the one obtained by fitting the output equation separately, as can be seen from the following regression:

$$\underset{}{y_t} = \underset{(.096)}{.476}\ (m_t - \underset{(.091)}{0.128}\ p_{ot} - \underset{(.091)}{(1 - 0.128)}\ \bar{p}_t)$$

$$\lambda = \underset{(.036)}{.902} \qquad R^2 = .903 \qquad DW - 1.23 \qquad \text{Period: } 1948I \text{ to } 1979II$$

The low value of the DW statistic suggests, however, that one should not place too much confidence in these estimates of the weight of p_o in the price index on which individuals base their consumption decisions.

While the output equation appears to be misspecified, the opposite is true for the equation describing the price level. Specification II which includes the output equation while allowing v_t to follow a first order autoregression, is not only not rejected by a model which includes the same explanatory variables without constraining their coefficients, but it is also accepted at the 99.2% significance level against a vector autoregression.

The results for this case are thus mixed. On the favorable side, the coefficients satisfy the model's restrictions and the specification of the pricing equation is basically not rejected by less restrictive hypotheses. Furthermore the hypothesis that prices are fully flexible

is rejected. On the other hand, the output equation appears to be misspecified and the construction of a price index that reflects the postulates of the model has probably not been achieved.

VII. Conclusions

This paper has presented evidence related to a specific model of sticky prices. In this model, prices are sticky because firms face a subjective cost to changing their prices. The model incorporates a number of specific assumptions about the functional forms of the demand functions, production fractions, etc. It therefore significantly reduces the set of outcomes that do not contradict the model. In particular, the implications of the model stand in sharp contrast to the implications of the Walrasian equilibrium with complete markets. In general, the data for the postwar U.S. do not contradict the model and, furthermore, do contradict the Walrasian equilibrium that would obtain under the same demand and production functions.

Two sets of tests were performed. First, I showed that relative prices of goods do not have the martingale property. Or, in other words, that in a period in which the expected real return of holding Treasury bills was always zero, the expected real return on the holding of goods could be predicted with past information. This test casts doubts on the explanatory power of the Walrasian equilibrium with complete markets. Instead, it validates the model insofar as the model predicts that changes in relative prices will be serially correlated. This test, however, is unable to distinguish between the model of this paper and

other models in which markets are not complete. In particular, the Lucas [1975] model can be modified to predict that changes in relative prices are correlated.

The second set of tests involves the estimation of the equilibrium paths of the price level and output implied by the model. These equilibrium paths must satisfy two types of testable restrictions. First, the estimated parameters must satisfy certain inequalities. Second, the model predicts that, if one were to estimate more parameters by adding explanatory variables, these added variables would not significantly contribute to the explanation of the price level and output. The estimation of this aggregate model was carried out both under the assumption that all prices are set by firms who face a subjective cost to changing prices and under the assumption that some prices are exogenous. The latter assumption produced results that are slightly more consistent with the model. In general, the estimated parameter satisfy the restrictions imposed by the model. Furthermore, when the output equation is excluded, less restricted models do not reject the model of this paper. Finally, the hypothesis that prices adjust instantaneously, under the maintained hypothesis about the functional forms of the demand and production functions, is rejected by the data. These three facts are taken to be evidence that the model ought to be taken seriously as an explanator of aggregate phenomena in the United States.

On the other hand, the output equation appears to be misspecified since, when it is included, the model is rejected by some of the models that are less restricted. This result must be contrasted with Barro's

[1978]. He could not reject his model when estimating only the output equation. Instead, when he included his price level equation, his estimates did not even satisfy the restrictions imposed by his model. Note that here the parameter estimates do satisfy the restrictions of my model even when the output equation is included.

Since this model does not just make predictions about the stochastic processes followed by the aggregate variables but, instead, starts by making predictions about individual prices and quantities, it would be desirable to estimate and test this model using microeconomic data. In particular, the ideal procedure would be to estimate jointly the equilibrium (represented by the movement of the aggregate variables) and the objective functions of individual firms (represented by the movement of firms specific variables).

Less ambitious undertakings would include the estimation of the effect on the aggregate variables of both particular exogenous prices and of shifts in the labor supply curve. The former could be achieved by disaggregating the consumer price index, the latter by estimating jointly a labor supply curve.

FOOTNOTES

1. This problem has been pointed out already by Nordhaus [1972].

2. Problems of this type have been solved by numerous authors including Kennan [1979] and Sargent [1979].

3. This definition is different from the National Income account definition of GNP since intermediate goods are counted in my definition of Y_t.

4. This assumption is made for expositional convenience only. As long as m follows some stochastic process whose first difference is stationary and which is driven by noise, the noise will generate fluctuations in relative prices.

5. Note that the effect of the difference between the price level at t-1 and the long run equilibrium price level as perceived at t-1 on relative prices does not vanish at the rate α. This is so because the price level itself is adjusting towards its long run equilibrium value. Therefore at (t+1) the impact of $(m_{t-1} - v + S/D - p_{t-2})$ on relative prices is α times the impact at t, plus γ^2 the impact at t-1. This latter effect is due to the fact that the price level at t+1 still will not have completely caught up with $(m_{t-1} - v + S/D)$.

6. It is for the same reason that the aggregate model was fitted separately to the whole price level and to a price index which excludes such items as food.

7. These correlations may be due in part to errors in the measurement of the price indices. In particular, not all those prices that constitute the ingredients of these indices are sampled every month. Therefore, an increase in all consumer prices by 10 percent in a given month may lead to an increase of less than 10 percent in the cpi for that month followed by subsequent increases in the cpi. Hence, lack of serial correlation in the changes of the true relative prices could be reflected by serially correlated changes in measured relative prices. However, it seems unlikely that these measurement errors are solely responsible for the large serial correlations reported in Table 1.

8. Note that the $\bar{\Psi}$'s are not equivalent to the Ψ's of (36) since the former are coefficients that apply to the first difference of m. Instead, the relationship between the $\bar{\Psi}$'s and the Ψ's is given by:

$$\Psi_1 = 1 + \bar{\Psi}_1$$

$$\Psi_2 = \bar{\Psi}_2 - \bar{\Psi}_1$$

$$\Psi_3 = -\Psi_2$$

9. Again, the $\hat{\Psi}$'s are not equal to the Ψ's of (36). The relationship between the two is given by:

$$\Psi_1 = \hat{\Psi}_1 \qquad \Psi_4 = 1$$

$$\Psi_2 = \hat{\Psi}_2 \qquad \Psi_5 = -\hat{\Psi}_1$$

$$\Psi_3 = 0 \qquad \Psi_6 = -\hat{\Psi}_2$$

10. The one surprising feature of this representation is that both the second and the fourth lag of $\hat{m}$ help to explain the current value of $\hat{m}$ while the third lag does not. Indeed, if one simply projects $\hat{m}$ on six lags, the coefficient of the third lag is insignificantly different from zero and very small, while the others have neither of these features.

11. The implied estimates of ρ are somewhat small. They are .002 when seasonally adjusted and .21 when seasonally unadjusted data were used. This low value for ρ is the reflection of the rather large coefficient estimates for δ. These lead to expected future money balances not being imported determinants of current prices. Instead only current money balances appear to be important in this respect. In turn, this suggests that firms are not overly concerned by the future and that they have a high discount rate.

12. The estimates for the discount factor are, once again, somewhat small (around .3).

Appendix

The Transformed Aggregate Data

This appendix presents the data used in the regressions reported in Sections V, VI and VII.

The variable m is the residual of a regression of the logarithm of seasonally adjusted M1 on a constant, a linear trend and a square trend. Instead, the variable $\hat{m}$ is constructed using the same procedure applied to seasonally unadjusted M1. The variable p_c is the residual of a regression of the logarithm of the seasonally adjusted cpi on a constant, a linear trend and a square trend. Meanwhile the variables $\hat{p}_c$, p_d and $\bar{p}$ are constructed applying the same procedure to the seasonally unadjusted cpi, the GDP deflator and the deflator for the output of the private nonfarm business sector respectively.

The variable p_o was constructed in two stages. First, the variable P_o was computed as the weighted average of the price deflators for the farm sector, the statistical discrepancy, the government sector, the set of the world and the household sector. The weights that were used were the proportion of the product of all five sectors accounted for by each individual sector. Second, p_o was constructed as the residual of the regression of the logarithm of P_o on a constant, a linear trend and a square trend.

Finally, the variable y is the residual of the regression of the logarithm of real GNP on a constant and a time trend. This variable can therefore be interpreted as being equal to the GNP gap.

TABLE 1. Quarterly Values of m

1947	1	-0.044059	-0.02864	-0.029932	-0.01764
1948	1	-0.019151	-0.028782	-0.029361	-0.034925
1949	1	-0.041929	-0.042279	-0.047253	-0.049355
1950	1	-0.042618	-0.030499	-0.024508	-0.01858
1951	1	-0.011144	-0.005066	0.00443	0.019401
1952	1	0.029074	0.033911	0.04041	0.045681
1953	1	0.046734	0.049504	0.046932	0.043456
1954	1	0.041921	0.039734	0.044587	0.049191
1955	1	0.056645	0.057609	0.056679	0.053141
1956	1	0.051197	0.048377	0.042977	0.04185
1957	1	0.037902	0.032364	0.026455	0.014808
1958	1	0.007178	0.012094	0.015316	0.020686
1959	1	0.027188	0.028529	0.026451	0.012913
1960	1	0.001076	-0.008101	-0.007634	-0.01335
1961	1	-0.017123	-0.016924	-0.019411	-0.018083
1962	1	-0.020606	-0.024704	-0.035392	-0.038201
1963	1	-0.037874	-0.037107	-0.036778	-0.035811
1964	1	-0.039305	-0.039386	-0.032846	-0.03056
1965	1	-0.033801	-0.036407	-0.035212	-0.028389
1966	1	-0.022558	-0.021099	-0.032948	-0.042263
1967	1	-0.043774	-0.041035	-0.028957	-0.025006
1968	1	-0.02335	-0.016611	-0.007954	0.001166
1969	1	0.00631	0.002658	-0.003762	-0.008743
1970	1	-0.012321	-0.013597	-0.013581	-0.012179
1971	1	-0.007648	0.001737	0.005329	-0.001154
1972	1	0.005024	0.009044	0.016278	0.024803
1973	1	0.031678	0.030381	0.029173	0.028042
1974	1	0.031744	0.027421	0.022509	0.019028
1975	1	0.009083	0.008297	0.011059	0.003036
1976	1	-0.001028	-0.000831	-0.006214	-0.003683
1977	1	-0.001401	0.000837	0.005946	0.007714
1978	1	0.007768	0.013818	0.016537	0.010021
1979	1	-0.012294	-0.010607		

TABLE 2. Quarterly Values of $\hat{n}$

1947	1	-0.039127	-0.043898	-0.024449	-0.003792
1948	1	-0.013474	-0.043664	-0.033433	-0.021107
1949	1	-0.035557	-0.056351	-0.052272	-0.03643
1950	1	-0.036289	-0.044278	-0.030224	-0.005054
1951	1	-0.002541	-0.018022	-0.004419	0.032273
1952	1	0.038578	0.022167	0.030393	0.059297
1953	1	0.0562	0.038384	0.036615	0.055399
1954	1	0.051529	0.029739	0.034429	0.060884
1955	1	0.065448	0.047982	0.046844	0.063794
1956	1	0.060107	0.039608	0.033219	0.052144
1957	1	0.045519	0.023655	0.017749	0.025123
1958	1	0.013131	0.003915	0.00746	0.031614
1959	1	0.032405	0.020002	0.018663	0.024762
1960	1	0.006042	-0.016462	-0.015928	-0.000871
1961	1	-0.011997	-0.025101	-0.028688	-0.00498
1962	1	-0.015411	-0.032454	-0.045408	-0.02537
1963	1	-0.031905	-0.045783	-0.046678	-0.022841
1964	1	-0.033129	-0.049251	-0.043386	-0.016538
1965	1	-0.0281	-0.045866	-0.045568	-0.014571
1966	1	-0.017539	-0.029081	-0.043246	-0.028845
1967	1	-0.04056	-0.048282	-0.038232	-0.012399
1968	1	-0.020527	-0.023376	-0.015951	0.013046
1969	1	0.008261	-0.003356	-0.011201	0.002517
1970	1	-0.010916	-0.019268	-0.020583	-0.001596
1971	1	-0.007678	-0.003289	-0.000628	0.009748
1972	1	0.003995	0.004162	0.010679	0.036018
1973	1	0.029934	0.02597	0.024687	0.038955
1974	1	0.028611	0.023589	0.018228	0.029628
1975	1	0.005216	0.004596	0.007303	0.01382
1976	1	-0.005846	-0.004035	-0.009282	0.007232
1977	1	-0.007321	-0.002191	0.002975	0.018585
1978	1	0.001853	0.010894	0.013567	0.021141
1979	1	-0.016191	-0.010153	-0.003256	0.00537

TABLE 3. Quarterly Values of ρ_c

1947	1	-0.141381	-0.125721	-0.102901	-0.074068
1948	1	-0.052653	-0.035769	-0.018501	-0.027637
1949	1	-0.036856	-0.037796	-0.046209	-0.049074
1950	1	-0.052219	-0.044964	-0.028264	-0.008812
1951	1	0.030225	0.038676	0.036868	0.050353
1952	1	0.052761	0.053846	0.058595	0.05768
1953	1	0.053208	0.05478	0.05695	0.056653
1954	1	0.056177	0.052179	0.046678	0.040205
1955	1	0.038501	0.034459	0.031488	0.03104
1956	1	0.027637	0.030375	0.036693	0.041362
1957	1	0.045222	0.049798	0.054164	0.054173
1958	1	0.061568	0.063354	0.057906	0.053596
1959	1	0.050264	0.046872	0.046167	0.04652
1960	1	0.042022	0.042027	0.036575	0.03706
1961	1	0.032644	0.025855	0.023362	0.018052
1962	1	0.015086	0.011862	0.007608	0.002884
1963	1	-0.001431	-0.007056	-0.008644	-0.013465
1964	1	-0.017385	-0.023679	-0.029822	-0.033497
1965	1	-0.038782	-0.040847	-0.046325	-0.050226
1966	1	-0.049762	-0.049689	-0.050518	-0.051684
1967	1	-0.057861	-0.062101	-0.061512	-0.06149
1968	1	-0.061374	-0.061814	-0.058979	-0.056759
1969	1	-0.055762	-0.050439	-0.047608	-0.043905
1970	1	-0.038793	-0.036088	-0.036556	-0.034176
1971	1	-0.037683	-0.0389	-0.041183	-0.047214
1972	1	-0.050718	-0.055498	-0.059408	-0.062998
1973	1	-0.060831	-0.051898	-0.045053	-0.034595
1974	1	-0.018434	-0.004391	0.010348	0.026774
1975	1	0.032277	0.03332	0.038527	0.041628
1976	1	0.038147	0.035007	0.034135	0.032179
1977	1	0.036914	0.041324	0.038875	0.036674
1978	1	0.040191	0.048924	0.054422	0.060506
1979	1	0.070824	0.08674		

TABLE 4. Quarterly Values of p_d

1947	1	-0.112714	-0.1008	-0.08513	-0.054151
1948	1	-0.037555	-0.027029	-0.013019	-0.017868
1949	1	-0.030383	-0.039328	-0.042708	-0.0443
1950	1	-0.049834	-0.04213	-0.01808	-0.003795
1951	1	0.024289	0.027135	0.024594	0.032388
1952	1	0.027876	0.024981	0.027161	0.036046
1953	1	0.034498	0.03283	0.038432	0.025735
1954	1	0.033845	0.033356	0.026039	0.026985
1955	1	0.03277	0.033406	0.035538	0.035881
1956	1	0.040932	0.04417	0.050398	0.053249
1957	1	0.059031	0.058412	0.062258	0.058285
1958	1	0.057239	0.05302	0.053221	0.050261
1959	1	0.051666	0.052897	0.051005	0.047503
1960	1	0.04827	0.043042	0.040606	0.035132
1961	1	0.026636	0.023824	0.020874	0.016353
1962	1	0.017418	0.012627	0.007709	0.005483
1963	1	0.001707	-0.005002	-0.010434	-0.013211
1964	1	-0.01752	-0.023343	-0.026545	-0.032627
1965	1	-0.033394	-0.03839	-0.040833	-0.044775
1966	1	-0.043566	-0.04128	-0.045723	-0.046444
1967	1	-0.049918	-0.056097	-0.057345	-0.055042
1968	1	-0.053013	-0.052472	-0.053375	-0.049722
1969	1	-0.049914	-0.048013	-0.0441	-0.042786
1970	1	-0.038402	-0.037669	-0.040464	-0.039145
1971	1	-0.035989	-0.033171	-0.036877	-0.04077
1972	1	-0.038757	-0.044075	-0.048564	-0.050272
1973	1	-0.048321	-0.044786	-0.039755	-0.03056
1974	1	-0.024668	-0.012202	0.001205	0.017118
1975	1	0.030455	0.03109	0.034535	0.036025
1976	1	0.030309	0.027428	0.024301	0.024616
1977	1	0.02387	0.027813	0.024278	0.02536
1978	1	0.025387	0.035108	0.037582	0.042835
1979	1	0.048804	0.055428	0.05844	0.063348

TABLE 5. Quarterly Values of $\hat{p}_c$

1947	1	-0.148558	-0.132792	-0.103463	-0.075037
1948	1	-0.058748	-0.041433	-0.01859	-0.027554
1949	1	-0.04186	-0.042438	-0.04549	-0.048223
1950	1	-0.056293	-0.048484	-0.026567	-0.007198
1951	1	0.027387	0.036427	0.039254	0.052112
1952	1	0.050801	0.052725	0.061184	0.059875
1953	1	0.052165	0.054339	0.06009	0.05905
1954	1	0.055804	0.052418	0.050135	0.042737
1955	1	0.038515	0.035402	0.035474	0.03374
1956	1	0.028138	0.03191	0.04079	0.044138
1957	1	0.046091	0.051849	0.058157	0.057187
1958	1	0.06268	0.065627	0.061864	0.056808
1959	1	0.051613	0.049349	0.049987	0.049695
1960	1	0.043565	0.044475	0.040326	0.040153
1961	1	0.034221	0.028152	0.026779	0.021171
1962	1	0.016533	0.013965	0.010871	0.005794
1963	1	-0.000159	-0.005158	-0.005586	-0.010886
1964	1	-0.016332	-0.022283	-0.026943	-0.031399
1965	1	-0.038143	-0.039712	-0.043929	-0.048657
1966	1	-0.04971	-0.048901	-0.048669	-0.050695
1967	1	-0.058301	-0.061346	-0.060585	-0.062376
1968	1	-0.062092	-0.061409	-0.059395	-0.057987
1969	1	-0.057484	-0.051114	-0.047884	-0.045289
1970	1	-0.041848	-0.037319	-0.037727	-0.036427
1971	1	-0.04072	-0.041339	-0.04359	-0.050413
1972	1	-0.054976	-0.059471	-0.06311	-0.066967
1973	1	-0.066112	-0.057439	-0.048874	-0.039215
1974	1	-0.025015	-0.010785	0.005445	0.020228
1975	1	0.024145	0.025517	0.032256	0.0336
1976	1	0.02859	0.026113	0.02704	0.023178
1977	1	0.025485	0.031418	0.030425	0.025855
1978	1	0.026878	0.036667	0.043991	0.047842
1979	1	0.056167	0.073462	0.089367	0.101479

TABLE 6. Quarterly Values of p_o

1947	1	0.028686	-0.02905	-0.028791	0.003601
1948	1	0.052341	0.108023	0.073915	0.045427
1949	1	-0.023434	-0.045345	-0.074258	-0.061701
1950	1	-0.104407	-0.071824	-0.013668	0.013325
1951	1	0.036111	0.017838	0.000437	0.042955
1952	1	0.014847	0.035353	0.038629	-0.006106
1953	1	-0.014874	-0.019263	-0.018355	-0.032211
1954	1	-0.014041	-0.020445	-0.023993	-0.030856
1955	1	-0.036134	-0.006022	-0.024806	-0.022755
1956	1	0.003726	0.025826	0.033298	0.035533
1957	1	0.025203	0.031994	0.026025	0.035695
1958	1	0.06448	0.038145	0.015678	0.011729
1959	1	0.036624	0.030774	0.023866	-0.002924
1960	1	0.010734	0.028341	0.039874	0.035781
1961	1	0.007275	-0.015462	-0.017276	-0.005524
1962	1	-0.012179	-0.028249	-0.025344	-0.00278
1963	1	-0.003768	-0.004222	-0.03755	-0.043681
1964	1	-0.058599	-0.061267	-0.046993	-0.014259
1965	1	-0.02412	-0.005577	-0.030908	-0.01679
1966	1	-0.015865	-0.028888	-0.017591	-0.034103
1967	1	-0.049837	-0.043206	-0.052562	-0.033117
1968	1	-0.014402	-0.033007	-0.013495	0.001953
1969	1	-0.006371	0.009788	0.019844	0.043972
1970	1	0.046107	0.032503	0.022492	0.004446
1971	1	0.0106	-0.005651	-0.004217	0.014408
1972	1	0.037692	0.010793	0.011798	0.011997
1973	1	0.038796	0.067586	0.076482	0.070358
1974	1	0.064673	0.036905	0.025803	0.019046
1975	1	0.030698	0.032284	0.034557	0.03886
1976	1	0.00978	0.001404	-0.023623	-0.033966
1977	1	-0.027308	-0.040038	-0.065663	-0.040975
1978	1	-0.028069	-0.018655	-0.024203	-0.015369
1979	1	0.002799	-0.005854	-0.044529	

TABLE 7. Quarterly Values of $\bar{p}$

1947	1	-0.138168	-0.123162	-0.102623	-0.076915
1948	1	-0.052019	-0.044304	-0.022305	-0.018649
1949	1	-0.024041	-0.034957	-0.035161	-0.040889
1950	1	-0.044912	-0.039987	-0.019986	-0.006896
1951	1	0.019388	0.021615	0.022054	0.029006
1952	1	0.029202	0.02765	0.030902	0.043691
1953	1	0.043402	0.043006	0.04409	0.033933
1954	1	0.041165	0.043478	0.036249	0.039909
1955	1	0.041859	0.040579	0.045344	0.048406
1956	1	0.049799	0.049551	0.056654	0.062044
1957	1	0.068686	0.064972	0.068384	0.064457
1958	1	0.06043	0.059166	0.059208	0.05912
1959	1	0.060307	0.061345	0.059462	0.056079
1960	1	0.055348	0.051745	0.048036	0.041484
1961	1	0.034834	0.033548	0.029423	0.019754
1962	1	0.018145	0.012355	0.006465	0.003169
1963	1	-0.001583	-0.009121	-0.014077	-0.015141
1964	1	-0.018995	-0.022963	-0.025731	-0.033861
1965	1	-0.036856	-0.045183	-0.048402	-0.055629
1966	1	-0.055216	-0.051167	-0.054925	-0.051297
1967	1	-0.051627	-0.059508	-0.060121	-0.05969
1968	1	-0.057055	-0.057033	-0.059551	-0.057551
1969	1	-0.055785	-0.054252	-0.050696	-0.050751
1970	1	-0.049903	-0.046021	-0.048866	-0.043365
1971	1	-0.043436	-0.041645	-0.044202	-0.048961
1972	1	-0.048802	-0.054866	-0.063051	-0.06439
1973	1	-0.067887	-0.066684	-0.063825	-0.051888
1974	1	-0.044252	-0.020159	-0.003404	0.014953
1975	1	0.03231	0.032088	0.036348	0.038691
1976	1	0.038427	0.036403	0.036411	0.037634
1977	1	0.035652	0.043489	0.045897	0.0445
1978	1	0.042181	0.05313	0.056178	0.061445
1979	1	0.066261	0.07809	0.08555	

TABLE 8. Quarterly Values of y

1947 1	-0.021791	-0.022915	-0.030482	-0.027014
1948 1	-0.02008	-0.018653	-0.017463	-0.015761
1949 1	-0.034533	-0.047253	-0.046727	-0.063913
1950 1	-0.027973	-0.010369	0.004772	0.018378
1951 1	0.023707	0.034091	0.045318	0.03839
1952 1	0.039269	0.031984	0.033764	0.048583
1953 1	0.055659	0.05343	0.038707	0.020382
1954 1	-0.001812	-0.014567	-0.008779	0.001449
1955 1	0.016487	0.022866	0.028722	0.03018
1956 1	0.017186	0.013656	0.005617	0.008591
1957 1	0.006886	-0.001017	-0.002775	-0.024479
1958 1	-0.052965	-0.054393	-0.039075	-0.022179
1959 1	-0.018641	-0.005566	-0.024861	-0.022977
1960 1	-0.011845	-0.022915	-0.035892	-0.049707
1961 1	-0.051943	-0.043886	-0.039656	-0.024588
1962 1	-0.018911	-0.014688	-0.015838	-0.022613
1963 1	-0.021738	-0.017916	-0.008386	-0.007413
1964 1	0.000578	0.00452	0.005583	0.0008
1965 1	0.013542	0.019634	0.0282	0.040473
1966 1	0.050155	0.048404	0.049044	0.04789
1967 1	0.040862	0.039141	0.042712	0.041839
1968 1	0.042847	0.051511	0.054622	0.048712
1969 1	0.049516	0.045336	0.040212	0.026114
1970 1	0.013851	0.005679	0.004371	-0.014112
1971 1	-0.000686	-0.002046	-0.003729	-0.003851
1972 1	0.005817	0.016103	0.020281	0.031979
1973 1	0.046041	0.03846	0.034039	0.030483
1974 1	0.011817	-0.001464	-0.016327	-0.039199
1975 1	-0.071537	-0.064675	-0.04833	-0.050513
1976 1	-0.033741	-0.036125	-0.037138	-0.037198
1977 1	-0.024635	-0.02156	-0.013288	-0.016476
1978 1	-0.020349	-0.009151	-0.009153	-0.004169
1979 1	-0.010007	-0.024602		

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